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THE USE OF STRICTLY DEFINED TERMS IN SUMMERTIME FORECASTS

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ABSTRACT

The desirability of using a fixed set of strictly defined terms to describe the areal distribution of summertime showers and thunderstorms in the daily State forecast is discussed, and the feasibility of doing so is investigated. The areal distribution of afternoon and evening showers in Colorado and the variations of the distributions among various sections of the State are determined. The relative frequency of occurrence of forecast categories is determined for two sets of arbitrarily defined forecast terms. Significant differences are found, on the average, in the number of showers when various forecasting terms are used to describe their occurrence.

A simple objective aid for forecasting the areal distribution of showers over the entire State of Colorado is presented to illustrate that there are meteorological variables that are related to the number of showers expected over an area which could form the basis for forecasts stated in strictly defined terms.

1. INTRODUCTION

The advocating of the use of and adherence to qualifying terms in forecasts which have definite meanings to describe the areal distribution of summertime shower activity is by no means new. Strictly defined terms have been used by the U. S. Weather Bureau in the Southeastern States in issuing shower and thunderstorm forecasts for use in cotton-spraying activities with apparently good success, and specific terms with definite definitions in terms of the percentage of area expected to be affected by showers are used for aviation forecasts. These two sets of terms are listed in tables 1 and 2 for comparison purposes.

As can be seen, the percentage definitions are for practical purposes identical. It can surely be assumed that if no showers or thunderstorms are forecast, the verifying definition under the aviation forecast terms should be 0 percent. The term "numerous" in the aviation list corresponds to the last two terms combined in the State list. For various reasons the author prefers the terminology used in the aviation list (with the term "none"

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TABLE 1.—*Aviation forecasting terms for describing the areal distribution of showers and thunderstorms*

Term	Percent of area expected to be affected
Few	Less than 15.
Widely scattered	15 to 30.
Scattered	31 to 45.
Numerous	Greater than 45.

TABLE 2.—*Forecasting terms for describing the areal distribution of showers and thunderstorms used in forecasts for cotton-spraying operations in the Southeastern States*

Term	Expected percent of areal coverage to receive measurable precipitation
Fair or partly cloudy with no mention of precipitation	0
Risk (or chance) of showers	0–15
Widely scattered showers	15–30
Scattered showers	30–45
Showers	45–75
General showers (or rain)	75–100

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added), and this list will be used in the following sections on the investigation of the areal distribution of showers in Colorado and the "verification" of forecasts issued in the past. The reasons for this preference may be correctly classified as personal opinion and need not be discussed here. Arguments about the relative merits of various terms for describing shower and thunderstorm activity could be, and are, carried on endlessly. Actually, it is relatively immaterial what *words* are used in such a list, the only criterion being that the terms imply a progressive increase in the areal coverage by shower activity. The important things are the percentage definitions of the terms and the strict adherence to the terms once they are decided upon and defined.

One purpose of this study is to reemphasize the desirability of using such a list in the State, or general, forecasts and to point out the necessity of determining the relative frequency with which the various terms should be used. These frequencies will vary with climatologically different regions, and therefore, should be determined for climatological regions, if not for the individual States. This study applies only to the State of Colorado and no attempt should be made to apply the results to other regions. Very similar results would undoubtedly be obtained for any of the States straddling the Continental Divide, however, and the results obtained for the lower elevations of Colorado may prove typical for the Plains States.

In addition to stressing the desirability of using a fixed set of strictly defined terms to describe summertime shower activity, this study points out the feasibility of doing so. Comparison of the more commonly used terms in the daily forecasts issued for Colorado with the daily areal distribution of showers shows that on the average there are significant differences in the number of showers when the different terms are used. Stated in another way, forecasters show skill in describing the areal distribution of showers and thunderstorms. A simple objective aid will be described in section 5, which illustrates that such forecasts, at least for an entire State, can be placed on a quantitative and objective basis.

In line with the above discussion, the specific objectives of this study may be stated as follows: 1. To determine the areal distribution of afternoon and evening showers in Colorado and the variations of the distributions between various sections of the State. 2. To set up specific limits or definitions for various forecast terms to describe the distribution of showers, or alternatively, to determine the relative frequency of occurrence of forecast categories if arbitrary limits are established to define the categories. 3. To determine if there were any significant differences in the number of showers when various forecasting terms were used to describe their occurrence during the period under study.

2. AREAL DISTRIBUTION OF SHOWERS IN COLORADO

The precipitation data used in the investigation were obtained from the hourly precipitation amounts in Colorado published by the U. S. Weather Bureau for July and August of 1951–54. The number of reporting stations used varied during these 8 months from 81 to 87. Any station which did not show a complete record for the entire month was eliminated.

The State was divided into four equal sectors (Northwest, Northeast, Southwest, and Southeast) by a line along the 105.5° W. meridian and a line along the 39th parallel of latitude. All stations which reported precipitation (0.01 inch or more) between the hours of 11 a. m. and midnight (MST) were counted for each day in each sector and converted into a percentage by division by the total number of stations utilized in each sector. These percentages shall hereafter be referred to as the *daily percentages*. To obtain the daily percentages in the East half of the State, it was then only necessary to add the number of stations reporting precipitation in the Northeast and Southeast quadrants and divide by the total number of stations in these two quadrants. Similarly, daily percentages were obtained for the West, North, and South halves of the State and for the entire State.

A further division of the State was made into Mountain areas and Lower Elevation areas. This division was somewhat arbitrary, but it is felt it serves the purpose adequately. The general criteria used to decide if a station were a Mountain station or a Lower Elevation station were: 1. East of the Divide all stations whose elevations are 6,000 feet or higher were considered Mountain stations. 2. West of the Divide all stations whose elevations are 7,000 feet or higher were considered Mountain stations. There were four major exceptions to this rule, namely: Monte Vista, Alamosa, and San Luis in the high, broad San Luis Valley, which is above 7,000 feet MSL, were listed with the Lower Elevation stations, while Eagle (elevation 6,497 feet), which is in a rather narrow canyon, was listed as a Mountain station. These divisions of the State are illustrated in figure 1, with the cooperative reporting stations utilized marked by a solid triangle.

Cumulative frequency distributions of the daily percentages were computed for the entire State, the East, West, North, and South halves of the State, and for the Mountain and Lower Elevation sectors. Figure 2 shows the cumulative frequency curves of the daily percentages for the North and South sectors, figure 3 for the East and West sectors, and figure 4 for the Mountains and Lower Elevations, and for the entire State.

There is apparently no significant difference between the distributions for the North and South halves of the State. The distribution of the daily differences in the daily percentages between the two portions of the State is shown in figure 5. This distribution seems to be very nearly normal with a mean difference of 0 percent and a standard deviation of about 15 percent. (Actual mean of distribution is −1 percent, and the standard deviation 14.5 percent.) The normality of this distribution and the zero mean would imply that there is no climatological difference in the density of shower activity between the North and South halves of the State in summer.

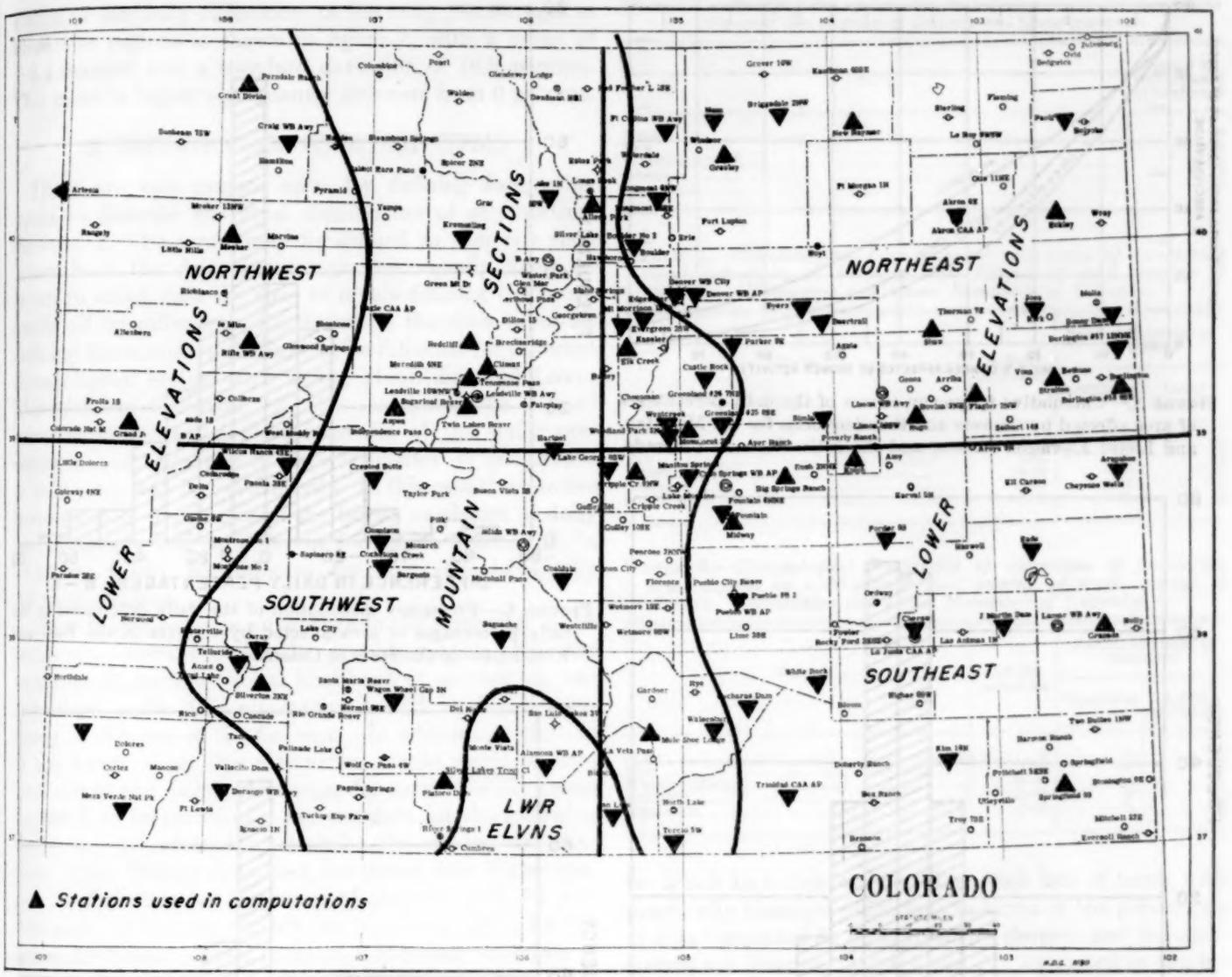

FIGURE 1.—Map showing division of State of Colorado into various sections and the Weather Bureau cooperative stations used to obtain precipitation data.

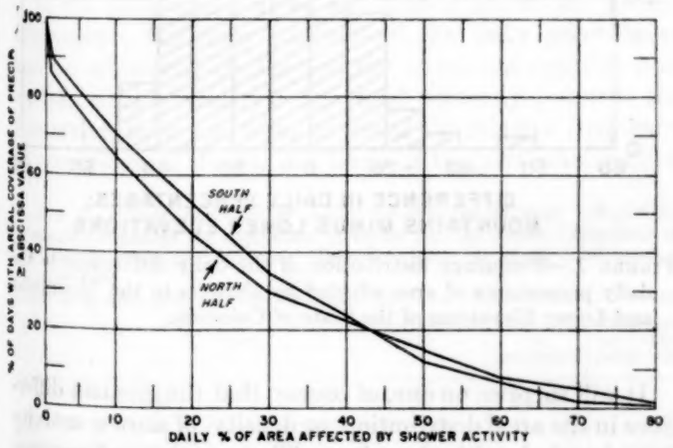

FIGURE 2.—Cumulative frequency curves of the daily percentages of area affected by showers and thunderstorms for the North and South halves of the State of Colorado.

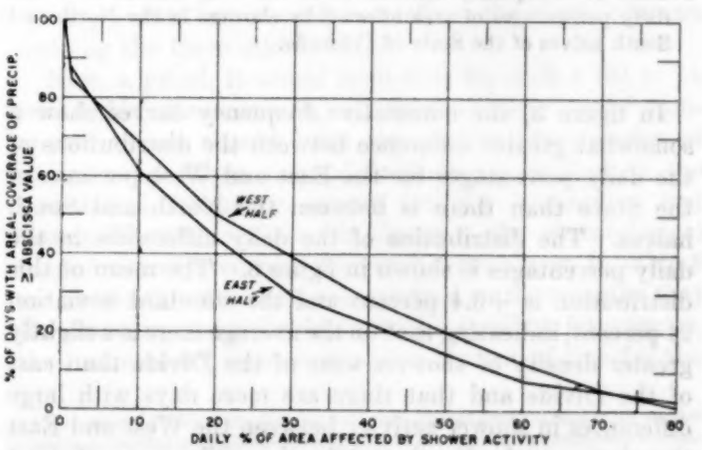

FIGURE 3.—Cumulative frequency curves of the daily percentages of area affected by showers and thunderstorms for the East and West halves of the State of Colorado.

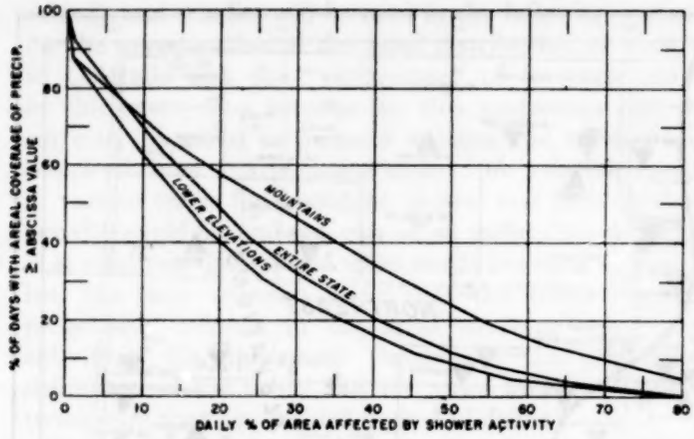
% OF DAYS WITH AREAL COVERAGE OF PRECIP. ≥ ABSCISSA VALUE
DAILY % OF AREA AFFECTED BY SHOWER ACTIVITY
MOUNTAINS
ENTIRE STATE
LOWER ELEVATIONS

FIGURE 4.—Cumulative frequency curves of the daily percentages of area affected by showers and thunderstorms for the Mountain and Lower Elevation sectors, and the entire State of Colorado.

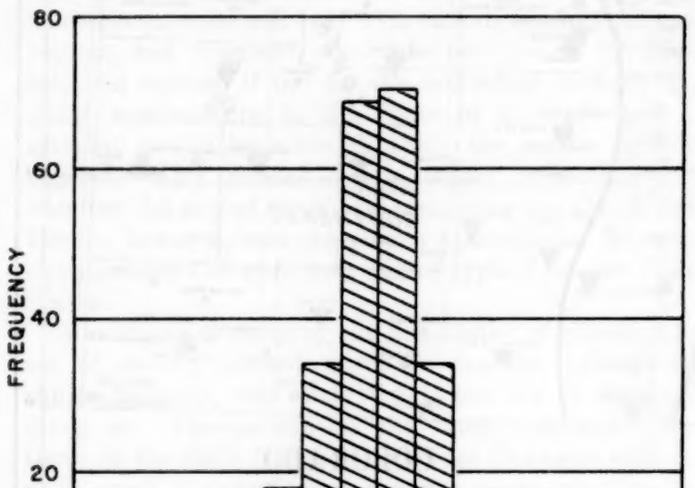

FIGURE 5.—Frequency distribution of the daily differences in the daily percentages of area affected by showers in the North and South halves of the State of Colorado.

In figure 3, the cumulative frequency curves show a somewhat greater difference between the distributions of the daily percentages for the East and West portions of the State than there is between the North and South halves. The distribution of the daily differences in the daily percentages is shown in figure 6. The mean of this distribution is +3.4 percent and the standard deviation 21 percent, indicating that on the average there is a slightly greater density of showers west of the Divide than east of the Divide and that there are more days with large differences in shower activity between the West and East than between the North and South. (The mean of +3.4 percent is significantly different from 0 percent at the 0.02 level.)

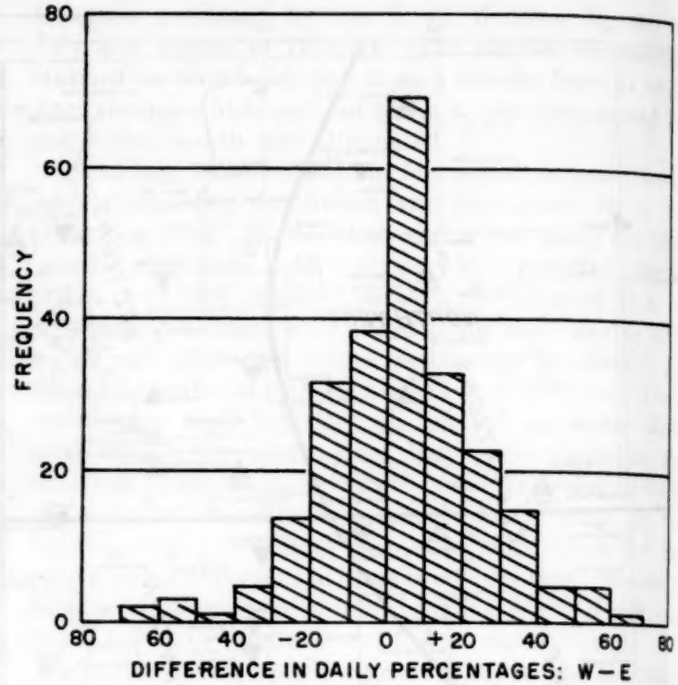

FIGURE 6.—Frequency distribution of the daily differences in the daily percentages of area affected by showers in the East and West halves of the State of Colorado.

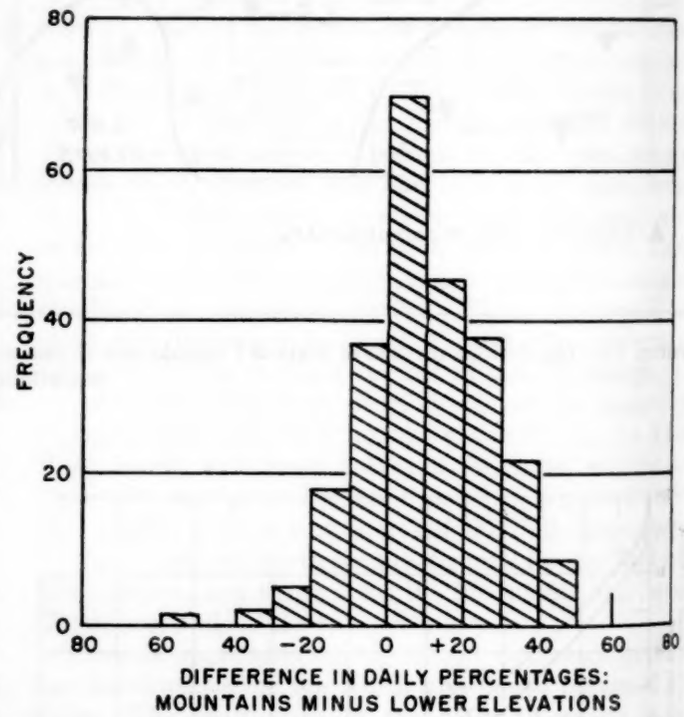

FIGURE 7.—Frequency distribution of the daily differences in the daily percentages of area affected by showers in the Mountains and Lower Elevations of the State of Colorado.

It will surprise no one, of course, that the greatest difference in the areal distribution, or density, of shower activity in Colorado is with elevation. The cumulative frequency curves for the Mountain stations and the Lower Elevation stations shown in figure 4 are quite different. The distri-

bution of the daily differences in the daily percentages in these two regions is shown in figure 7, with a mean of +9.4 percent and a standard deviation of 16.8 percent. This mean is highly significantly different from 0 percent.

3. DEFINITION OF FORECAST TERMS

There are two courses open for defining forecasting terms to describe the areal distribution of summertime showers: 1. The terms may be defined so that the class intervals of the daily percentages are equally likely to occur, in which case the class intervals defining the terms would all be different. Furthermore, the class intervals defining the terms would have to be different for different climatological sectors such as the Mountains and Lower Elevations of Colorado. 2. The terms may be defined using arbitrary equal class intervals of the daily percentages and then the relative frequency of occurrence of each term may be determined. In this case the relative frequencies of occurrence of the terms, or classes of daily percentages, would be different from each other, and, in addition, would be different for two climatologically different sections.

There might be some advantage to the forecaster if the terms were defined under the first alternative since the terms would have an equal likelihood of occurrence, but definitions under this alternative would be highly confusing to the user of the forecast. In addition, definition of the terms under this alternative would result in class intervals of the daily percentages for several of the terms too small to be practical. For example, let the following five terms be selected to describe the shower activity: None, Few, Widely Scattered, Scattered, and Numerous, and let their relative frequency of occurrence be 20 percent each. From the cumulative frequency curve for the Lower Elevations shown in figure 4 the class intervals of daily percentage to define these terms shown in table 3 would be obtained. Obviously, the intervals of 4 to 11 percent and 12 to 20 percent are too small for practical purposes, and 35 percent seems to be rather low for the lower limit of "numerous" showers.

If the forecasting terms are defined under the second alternative, the class intervals of the daily percentages can be arbitrarily chosen and the terms can apply to any section of the country. It would certainly behoove the forecaster, however, to be aware of the relative frequency of occurrence of the various terms in the particular section for which he is forecasting. Two such lists of terms with practically identical definitions in terms of the percentage of area [2] expected to be affected by showers and thunderstorms are listed in tables 1 and 2. As stated in the introduction the aviation list is preferred, and this list, with the term "none" added, is repeated in table 4 with the indicated definitions in terms of the areal coverage of showers. The addition of "none" to the list alters the definitions of the "few" and "widely scattered" terms by 1 percent, but actually equalizes the class intervals defining the three middle terms.

Now, a priori, it would seem that for such a list to be reasonable, the extremes, namely the "none" and "numerous" terms, should have the smallest frequencies of occurrence. When these definitions are applied to the cumulative frequency curves for the Mountains and Lower Elevations shown in figure 4 the climatological frequencies of occurrence for each term shown in table 5 are obtained. As can be seen, judged on the criterion that the extreme terms should have the smallest frequencies, the "numerous" term is considerably out of line for the

TABLE 3.—*Class intervals of daily percentages of area affected by showers required for definition of terms for the Lower Elevations of Colorado when each term is allowed to have an equal likelihood of occurrence*

Term	Frequency of occurrence	Class interval of daily percentage
	Percent	
None	20	<4
Few	20	4–11
Widely scattered	20	12–20
Scattered	20	21–35
Numerous	20	>35

TABLE 4.—*Modified list of aviation forecasting terms for describing the areal distribution of showers and thunderstorms*

Term	Percent of area expected to be affected
None	0
Few	1–15
Widely scattered	16–30
Scattered	31–45
Numerous	>45

TABLE 5.—*Climatological frequencies of occurrence of forecasting terms defined by a 15-percent class interval of areal coverage of showers. (Mountains and Lower Elevations of Colorado)*

Term	Defining percentage	Percent frequency of occurrence	
		Mountains	Lower elevations
None	0	12	12
Few	1–15	24	38
Widely scattered	16–30	18	25
Scattered	31–45	17	13
Numerous	>45	29	12

TABLE 6.—*Climatological frequencies of occurrence of forecasting terms defined by a 20-percent class interval of areal coverage of showers. (Mountains and Lower Elevations of Colorado)*

Term	Defining percentage	Percent frequency of occurrence	
		Mountains	Lower elevations
None	0	12	12
Few	1–20	30	48
Widely scattered	21–40	24	24
Scattered	41–60	19	12
Numerous	>60	15	4

[2] It is assumed in this study that the percentage derived from the ratio of the number of stations reporting precipitation to the total number of stations is a reasonable estimate of the percentage of area affected by shower activity. While this assumption is open to question since the stations are far from uniformly distributed, it is the only such estimate available.

TABLE 7.—*Climatological frequencies of occurence of forecasting terms defined by a 15-percent class interval of areal coverage of showers. (Entire State of Colorado)*

Term	Defining percentage	Percent frequency of occurrence
None	0	7
Few	1–15	35
Widely scattered	16–30	26
Scattered	31–45	16
Numerous	>45	16

TABLE 8.—*Climatological frequencies of ocurrence of forecasting terms defined by a 20-percent class interval of areal coverage of showers. (Entire State of Colorado)*

Term	Defining percentage	Percent frequency of occurrence
None	0	7
Few	1–20	45
Widely scattered	21–40	27
Scattered	41–60	15
Numerous	>60	6

Mountains and even at Lower elevations the frequency for "numerous" is practically the same as for "scattered".

This situation can be remedied by defining the terms by a larger interval, say 20 percent rather than 15 percent. If this is done, the definitions and frequencies of occurrence shown in table 6 are obtained. With these definitions the "none" and "numerous" terms have the least frequencies of occurrence. Another advantage of using the 20-percent interval for definition is that the approximate midpoint of each term falls on a percentage that is a multiple of 10, and therefore is more easily remembered. "Scattered" for instance, would mean that on the average 50 percent of the area would be affected by showers.

To obtain an estimate of the relative frequencies of the terms for sections of the State in which both Mountain and Lower Elevation stations are included, the cumulative frequency curve of the daily percentages for the entire State was used. Applying the definitions of the forecasting terms to this curve, shown in figure 4, the frequencies shown in tables 7 and 8 are obtained. It will be noted that when the definitions are based on the 15-percent interval the frequency of occurrence of the "numerous" category is equal to the "scattered" category.

4. COMPARISON OF FORECAST TERMS WITH DAILY PERCENTAGES

The daily forecasts for "this afternoon and evening" which are released at 0830 MST were inspected and the qualifying terms used to describe the afternoon and evening shower and thunderstorm activity were tabulated. The list of terms encountered in this forecast during the 8 months under study, with the number of times each was used, is shown in table 9. The total of the terms used exceeds the number of days (248) because more than one term was sometimes used in the same forecast. This is

TABLE 9.—*List of qualifying terms used to describe expected shower activity "this afternoon and evening" encountered in the forecast for the State of Colorado which is released at 0830 MST. (July and August 1951–54, inclusive)*

Forecast term	Frequency of use
None (this term is never used specifically, but is implied when showers or thunderstorms are not mentioned in the forecast)	45
Few	6
Few isolated	36
Few widely scattered	29
Few scattered	16
Few local	1
Few scattered local	2
Widely scattered, isolated	1
Widely scattered	84
Scattered	65
Occasional showers	2
Showers and thunderstorms (no qualifying term)	2

TABLE 10.—*Forecasting terms used to compare with the observed daily percentage of areal coverage of showers*

Forecast term	Frequency of use
None	45
Few isolated	42
Few widely scattered	29
Few scattered	16
Widely scattered	84
Scattered	65

cially true of the "none" forecasts. There were only days on which no showers or thunderstorms were mentioned for the entire State, but on 27 days the forecast designated certain portions of the State to receive showers, implying none for the rest of the State; thus the total number of "none" forecasts is increased to 45.

For comparison with the observed daily percentages, only those terms with an appreciable frequency were utilized. The six cases of "few" were considered as having the same meaning as "few isolated" and included with the latter term. The other low frequency terms were ignored. This left the terms listed in table 10 to compare with the observed daily percentages.

The daily percentages were tabulated under one of the terms depending upon which term was used to describe the shower activity. If the forecast was for the entire State, the percentage for the entire State was used for verification. If the forecast designated certain portions of the State, the percentages in those portions were used. For example, if a forecast read: "Scattered afternoon and evening showers and thunderstorms Northeast," the percentage for the northeast was listed under the "scattered" category and the percentage for the balance of the State was computed and listed under the "none" category.

Cumulative frequency distributions of the daily percentages were then made for each of the six terms listed in table 10. The unsmoothed curves representing these cumulative frequency distributions are shown in figures 8 and 9, with the curves for "none," "few isolated" and "scattered" on figure 8, and the curves for "few scattered," "few widely scattered," and "widely scattered" in figure 9. It is obvious that there are no significant differences among the three curves in figure 9, and that the three terms are

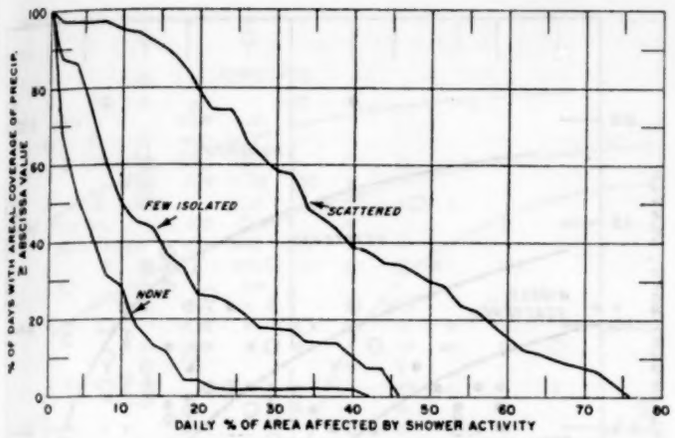
% OF DAYS WITH AREAL COVERAGE OF PRECIP. ≥ ABSCISSA VALUE
DAILY % OF AREA AFFECTED BY SHOWER ACTIVITY
FEW ISOLATED
SCATTERED
NONE

FIGURE 8.—Cumulative frequency curves of the daily percentages of area affected by showers and thunderstorms when the indicated forecasting terms were used to describe the shower activity expected.

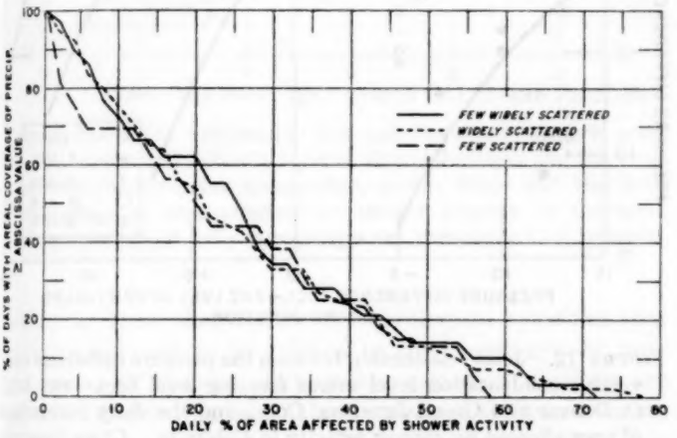
% OF DAYS WITH AREAL COVERAGE OF PRECIP. ≥ ABSCISSA VALUE
DAILY % OF AREA AFFECTED BY SHOWER ACTIVITY
FEW WIDELY SCATTERED
WIDELY SCATTERED
FEW SCATTERED

FIGURE 9.—Cumulative frequency curves of the daily percentages of area affected by showers and thunderstorms when the indicated forecasting terms were used to describe the shower activity expected.

either synonymous in the forecaster's mind, or if a distinction does exist, it is too fine to be practical. The frequencies of the daily percentages under these three forecast terms were therefore combined into one distribution which is shown in figure 10. Smooth curves were drawn by eye to fit the rough curves in figures 8 and 10, and are shown in figure 11.

TABLE 11.—*A number of statistical parameters obtained from the four distributions shown in figure 11*

	Forecast term			
	None	Few isolated	Combination of "widely scattered," "few widely scattered," and "few scattered"	Scattered
Number of cases	45	42	129	65
Mean	6	15	25	37
Median	4	10.5	20	34
Range	0–41	0–45	0–76	0–72
Standard deviation	7.6	13.4	17.3	19.0

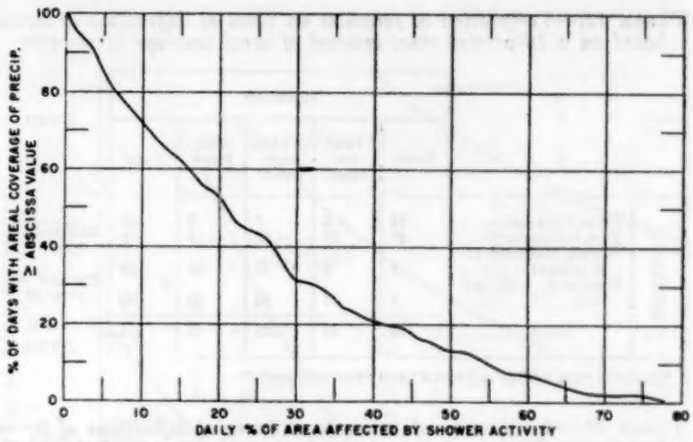

FIGURE 10.—Cumulative frequency curve of the daily percentage of area affected by showers and thunderstorms for the terms "few scattered," "few widely scattered," and "widely scattered" combined.

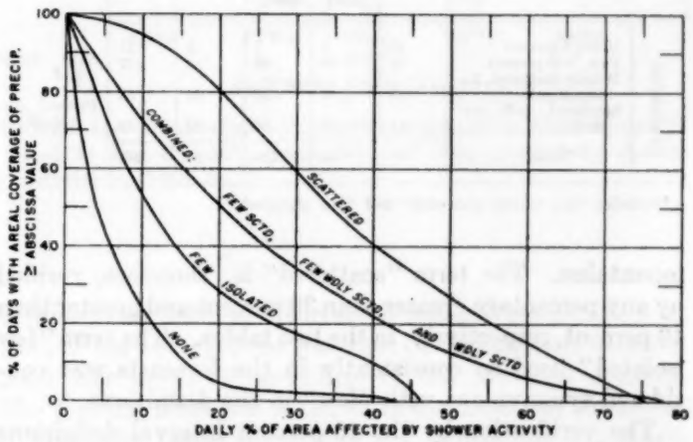

FIGURE 11.—Smoothed cumulative frequency curves of the daily percentage of the area affected by showers and thunderstorms when the indicated forecasting terms were used to describe the shower activity expected.

In table 11 are a number of statistical parameters derived from the four distributions. Tests of the differences between the means of these distributions show that the differences are all statistically significant.

While a verification of the forecasts on the basis of the arbitrary equal class intervals defined in the preceding section may not be entirely fair since the forecasters did not necessarily have in mind these particular limits when the forecast was made, such a verification is of interest, nonetheless. The contingency tables derived from the verification of the forecasts on the basis of the two sets of definitions in the preceding section are shown in tables 12 and 13. The term "numerous" was never used during the 8 months involved in this study, and while "showers and thunderstorms" without any qualifying terms can be considered equivalent to "numerous," such forecasts were made only twice and it would hardly be fair to the forecasters to include this category in this verification since daily percentages of greater than 45 percent occurred 31 times at lower elevations and as high as 68 times in the

TABLE 12.—*Verification of forecasts on basis of definitions of terms based on a 15-percent class interval of areal coverage of showers*

		FORECAST					
		None	Few isolated	Widely scattered*	Scattered	Total	
OBSERVED	None, 0 percent	13	5	7	2	27	Skill score: 0.18
	Few, 1–15 percent	27	22	42	5	96	
	Widely scattered 16–30 percent	4	8	36	20	68	Percent correct: 39
	Scattered, >30 percent	1	7	44	38	90	
	Total	45	42	129	65	281	

*Includes "few widely scattered" and "few scattered."

TABLE 13.—*Verification of forecasts on basis of definitions of terms based on a 20-percent class interval of areal coverage of showers*

		FORECAST					
		None	Few isolated	Widely scattered*	Scattered	Total	
OBSERVED	None, 0 percent	13	5	7	2	27	Skill score: 0.15
	Few, 1–20 percent	31	26	56	14	127	
	Widely scattered, 21–40 percent	0	7	37	24	68	Percent correct: 36
	Scattered, >40 percent	1	4	29	25	59	
	Total	45	42	129	65	281	

*Includes "few widely scattered" and "few scattered."

mountains. The term "scattered" is, therefore, verified by any percentage greater than 30 percent and greater than 40 percent, respectively, in the two tables. The term "few isolated" used so consistently in the forecasts was considered synonymous with "few" in the definitions.

The verification by the 15-percent interval definitions seems to show a slight advantage on this series of forecasts, but the difference is probably not significant. The fact that skill is shown in these forecasts indicates that it is highly probable that the skill score would have been considerably greater if either of these sets of definitions had been in the minds of the forecasters, and especially if the forecasters had been aware of the relative frequency of occurrence of the various terms. As can be seen, for instance, the "widely scattered" term (or its equivalent "few widely scattered" or "few scattered") was used out of all proportion to its actual frequency of occurrence and the term "few" ("few isolated") not often enough under either set of definitions. It cannot be concluded, however, that these terms were actually used "too often" or "too little" since the defining percentages were applied to the forecasts after they were made. It tends to stress, however, one of the main points of this paper, namely: no one knows, including the forecasters themselves, exactly what is implied by the forecast terminology in terms of the areal coverage of shower activity, or the relative probability of being rained on.

5. AN OBJECTIVE AID

Defining a list of forecasting terms is one thing; the ability to differentiate between the daily areal coverage

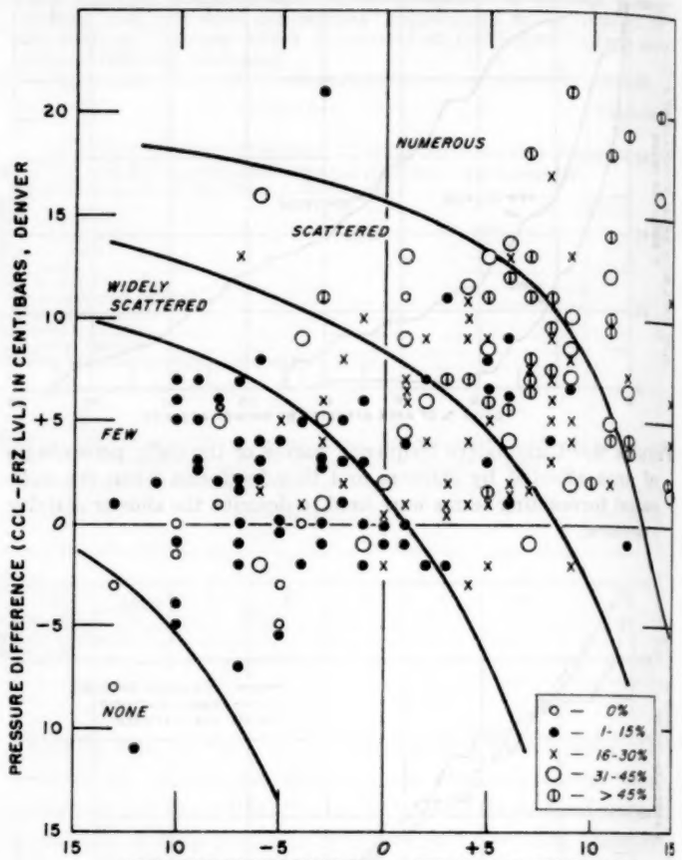

FIGURE 12.—Joint relationship between the pressure difference convective condensation level minus freezing level (CCL—FRZ LVL) at Denver and Grand Junction, Colo., and the daily percentage of area affected by shower activity in Colorado. Class intervals of daily percentages are represented by symbols.

of shower activity (or more precisely to differentiate between the daily percentages of stations affected by showers) is quite another. The definitions should not be primarily dependent upon the forecaster's ability to differentiate between them, but it is apparent that they must be to a certain extent. For instance, it would not be practical to have too long a list which would necessitate a small class interval of percentage for definition. Percentage definitions of any sort would be useless unless there is evidence that skill exists, or potentially exists, in making such differentiations. Such evidence has been presented in the preceding sections by illustrating that significantly different distributions of the daily percentages are obtained for the more commonly used terms, and by showing that positive skill results when arbitrary percentage definitions of terms are applied to a series of forecasts that were not necessarily based on the definite limits involved in the definitions.

As further evidence that the differentiation might be made with reasonable accuracy, and in fact might be placed on a more sound, quantitative basis, a simple objective method is described below. This is by no means an exhaustive study of the problem, but is presented

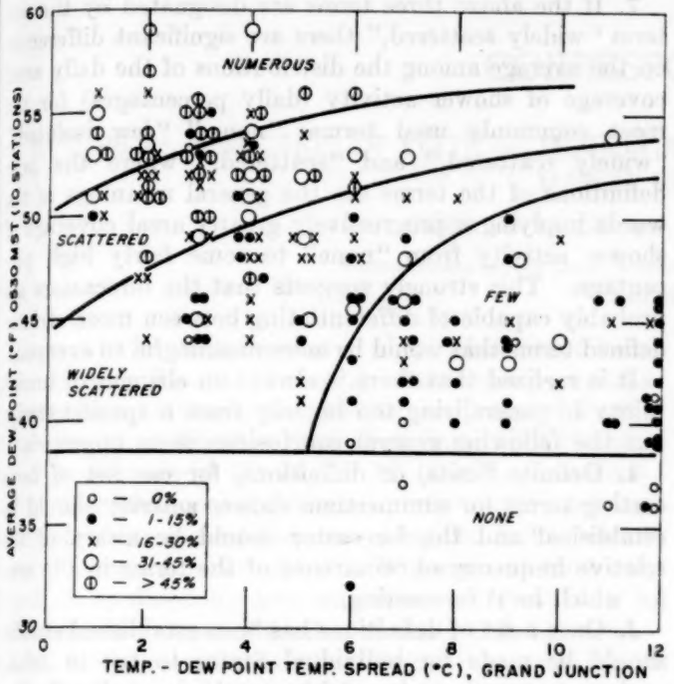

FIGURE 13.—Joint relationship between the minimum dew point spread in the 700–500-mb. layer at Grand Junction and the average surface dewpoint temperature in the State and the daily percentage of area affected by shower activity in Colorado. Class intervals of daily percentages are represented by symbols.

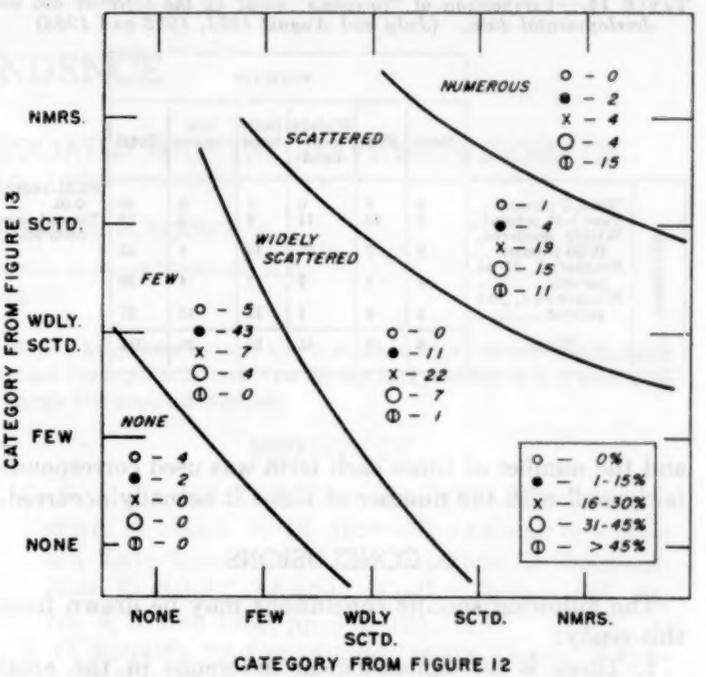

FIGURE 14.—Joint relationship between categories from figures 12 and 13 and the daily percentages of area affected by shower activity in Colorado.

merely to show that certain meteorological variables that have been found to be related to the occurrence or nonoccurrence of shower activity at particular localities are apparently also related to the number of showers over an area. This aid is based on only 6 summer months (July and August 1951, 1952, and 1954), and has not been tested on independent data, and in addition, applies to the entire State. The results are encouraging, however, and such a study should be a definite aid in deciding which strictly defined term to use to describe the areal distribution of showers on a given day.

Four variables were combined graphically and related to the observed daily percentages for the entire State of Colorado. These variables were:

1. Difference in pressure (in centibars) between the convective condensation level and the freezing level at Grand Junction, Colo. (CCL minus FRZ LVL).
2. Same as 1 for Denver, Colo.
3. Minimum spread between the temperature curve and the dew point temperature curve in the layer 700–500 mb. at Grand Junction, Colo.
4. Average of surface dewpoint temperatures at 10 stations in Colorado (or very near the border). (Grand Junction, Craig, Leadville, Alamosa, Trinidad, Pueblo, Denver, Akron, and Lamar, Colo., and Farmington, N. Mex.)

These variables were based on, or computed from, the 0530 MST surface observations and the 2000 MST upper-air soundings of the previous evening. In computing the convective condensation levels at Grand Junction and Denver, the 0530 MST surface dewpoint temperature at each of the two stations was used in conjunction with the 2000 MST upper-air sounding of the previous evening. The freezing level was taken from the 2000 MST sounding.

The daily percentages were not plotted on the charts as such, but instead symbols were used to represent class intervals of the percentages corresponding to the 15-percent class interval definitions of forecasting terms. These symbols are listed within each chart.

Figure 12 shows the joint relationship between the pressure differences (CCL minus FRZ LVL) at Grand Junction and Denver and the daily percentages. The chart was divided into five regions in which, as nearly as possible, the frequency of occurrence of one symbol (or class interval of percentage) was greater than the rest. The regions were then labeled "none," "few," etc., according to the dominant symbol or class interval.

A similar analysis was performed on figure 13 relating the other two variables to the daily percentages. Categories from these two charts were obtained for each case and used as coordinates of figure 14. The individual symbols are not plotted on this chart since a large number of cases fall at the discrete points determined by the categories used as coordinates. The distributions of the symbols in the regions indicated on the chart are listed, however, to show the stratification achieved.

Table 14 is a comparison of "forecasts" obtained from figure 14, and the observed percentages, and indicates a skill score of 0.40. It will be noted that this is a 5 by 5 contingency table, with the term "numerous" included,

TABLE 14.—*Verification of "forecasts" made by the objective aid on developmental data. (July and August 1951, 1952 and 1954)*

		FORECAST						
		None	Few	Widely scattered	Scattered	Numerous	Total	
OBSERVED	None, 0 percent	4	5	0	1	0	10	Skill score: 0.40.
	Few, 1–15 percent	2	43	11	4	2	62	Percent correct: 55.
	Widely scattered, 16–30 percent	0	7	22	19	4	52	
	Scattered, 31–45 percent	0	4	7	15	4	30	
	Numerous, >45 percent	0	0	1	11	15	27	
	Total	6	59	41	50	25	181	

and the number of times each term was used corresponds fairly well with the number of times it actually occurred.

6. CONCLUSIONS

The following specific conclusions may be drawn from this study:

1. There is no climatological difference in the areal distribution of showers and thunderstorms between the North and South portions of the State of Colorado.

2. There is a small, but significant, difference in the distributions in the East and West portions of the State.

3. There is a large and highly significant difference between the number of showers over the Mountain sectors and over the Lower Elevation sectors.

4. Defining forecast terms to describe the distribution of summertime showers by arbitrary equal intervals of percentage of stations (or percentage of area) affected by showers is a better procedure than to define the terms in such a way that they have an equal likelihood of occurrence.

5. Definition of terms by a class interval of 20 percent has certain advantages over the definitions using a class interval of 15 percent. While this conclusion is drawn from this specific study of Colorado, it is believed it is equally valid for other regions.

6. The forecasting terms "few widely scattered," "few scattered," and "widely scattered" apparently cannot be differentiated by the forecasters and therefore one term would suffice to describe the shower activity expected.

7. If the above three terms are designated by the one term "widely scattered," there are significant differences on the average among the distributions of the daily areal coverage of shower activity (daily percentages) for the most commonly used terms: "none," "few isolated," "widely scattered," and "scattered," where the only definitions of the terms are the general meanings of the words implying a progressively greater areal coverage of shower activity from "none" to some fairly high percentage. This strongly suggests that the forecasters are probably capable of differentiating between more strictly defined terms that would be more meaningful to everyone.

It is realized that there is always an element of uncertainty in generalizing too broadly from a specific study, but the following general conclusions seem appropriate:

1. Definite limits, or definitions, for *one* set of forecasting terms for summertime shower activity should be established and the forecaster should be aware of the relative frequency of occurrence of the terms in the area for which he is forecasting.

2. Once a set of definitions has been established studies should be made for individual States to try to relate various meteorological variables to the areal distribution of shower activity. Such studies would not, of course, solve the many problems involved in adequately describing the distribution of showers over an area, but would aid in placing the decision of which term to use on a more quantitative basis.

3. Once a set of definitions has been adopted, it should be thoroughly publicized so that the users of the forecast (the public) will know what a forecast means. Perhaps it is too optimistic to expect the public to become educated as to the meaning of the terms, but it is of equal importance that more precise definitions of terms be used so that the forecasters themselves know what a forecast means, and a more sound basis for verification is established. Improvement in forecasts can hardly be accomplished unless the forecasts are stated in terms that can be reasonably verified.

ACKNOWLEDGMENT

The assistance of Mrs. Virginia Marmaduke in processing data and construction of charts is gratefully acknowledged.

CORRESPONDENCE

NUMERICAL FORECASTS OF VERTICAL MOTION ASSOCIATED WITH THE HEAVY SNOWSTORM OF MARCH 18–19, 1956

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June 25, 1956

A report by us, which appeared in the March 1956 issue of the *Monthly Weather Review* [1], contains on page 119 a reference to a 1,000-mb. prognostic chart prepared by the Joint Numerical Weather Prediction Unit (JNWP) prior to the occurrence of the March 18–19 east-coast snowstorm. Our statement was intended only to call attention to the objective indications concerning the future movement of a surface Low located in Wisconsin at 1500 GMT March 17, as shown by data assembled as of that time.

Subsequent to the publication of this article our attention has been directed to another 24-hour prognostic chart routinely prepared by that Unit on an electronic computer; namely, a prediction of the vertical motion to be expected at the 800-mb. level at 1500 GMT March 18, 1956. This chart is shown in figure 1 wherein it will be seen that a center of positive (upward) vertical motion is located over Delaware. Such forecasts of vertical motion, which are implicit in any numerical system for forecasting synoptic development [2], were originally considered by-products of a system aimed at forecasting the pressure patterns. However, they may well be one of the most important contributions which can be made to the problem of forecasting precipitation by numerical means [3].

We are pleased to have this opportunity to bring to the attention of readers of the *Monthly Weather Review* this information which suggests that the vertical motion, as predicted, might have furnished a valuable clue to the subsequent storm track, in contrast to the lack of such information in the numerical prognostic 1,000-mb. chart. In addition it may have provided a valuable clue to the precipitation forecast and suggests that forecasters could obtain some valuable help from the evaluations of future vertical motion prospects thus made available rather than to attempt to apply the 1,000-mb. numerical forecasts.

The official weather forecasts released by this and other offices of the Weather Bureau for this storm are a matter of record. The first official Weather Bureau bulletin, which forecast the magnitude of the snow which occurred, was released at 1400 GMT, March 18, 1956, by this office (Washington National Airport). It reads as follows:

A disturbance that is located in West Virginia this morning will move eastward across central Virginia today and reach the Maryland coast by tonight and then move northeastward during the night. From 2 to 4 inches of snow is expected to accumulate across northern West Virginia, northwestern Virginia, and through the interior of Maryland, with lesser amounts over the remainder of northern Virginia and the Eastern Shore of Maryland. Amounts of snow expected to be greater toward the northeast with 3 to 5 inches through eastern Pennsylvania and New Jersey and possibly 4 to 6 inches on through Connecticut tonight.

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2. R. C. Sutcliffe, "A Contribution to the Theory of Synoptic Development," *Quarterly Journal of the Royal Meteorological Society*, vol. 73, Nos. 317–318, 1947, pp. 370–383.
3. J. Smagorinsky and G. O. Collins, "On the Numerical Prediction of Precipitation," *Monthly Weather Review*, vol. 83, No. 3, March 1955, pp. 53–68.

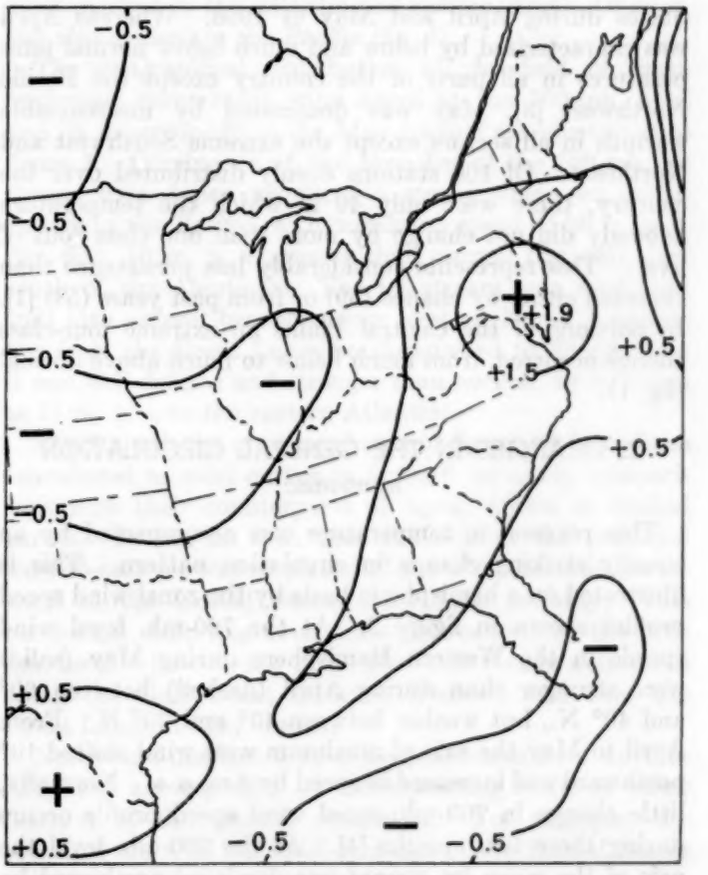

FIGURE 1.—JNWP 24-hr. prognostic vertical motion (cm. sec.$^{-1}$) at 800 mb. for 1500 GMT, March 18, 1956.

THE WEATHER AND CIRCULATION OF MAY 1956[1]

Another April–May Reversal

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1. TEMPERATURE REVERSAL IN THE UNITED STATES

In studying the annual course of month-to-month persistence in the United States, Namias [1] found that April–May was characterized by less persistence than any other pair of months except October–November. This tendency for change in long-period weather regimes was evidenced by monthly anomalies of precipitation, surface temperature, and 700-mb. height. Recent years have furnished additional examples of April–May reversals, particularly in 1954 [2].

This year another striking change in monthly weather and circulation occurred from April to May. This is well illustrated in figure 1, which compares the monthly mean temperature anomalies observed in the United States during April and May of 1956. Whereas April was characterized by below and much below normal temperatures in all parts of the country except the Pacific Northwest [3], May was dominated by unseasonable warmth in all sectors except the extreme Southwest and Northeast. Of 100 stations evenly distributed over the country, there were only 49 in which the temperature anomaly did not change by more than one class (out of five). This represents considerably less persistence than expected either by chance (59) or from past years (58) [1]. In portions of the Central Plains an extreme four-class change occurred, from much below to much above normal (fig. 1).

2. CHANGES IN THE GENERAL CIRCULATION

HEMISPHERIC

This reversal in temperature was accompanied by an equally striking change in circulation pattern. This is illustrated on a hemispheric basis by the zonal wind speed profiles shown in figure 2. At the 700-mb. level wind speeds in the Western Hemisphere during May (solid) were stronger than during April (dashed) between 60° and 40° N., but weaker between 40° and 20° N. From April to May the axis of maximum west wind shifted 10° northward and increased in speed by 4 m. p. s. Normally, little change in 700-mb. zonal wind speed profile occurs during these two months [4]. At the 200-mb. level the axis of the mean jet stream was displaced northward by over 20°, from about 25° N. in April (dashed) to about 48° N. in May (solid). As at 700 mb., wind speeds increased from April to May between 60° and 40° N., and decreased to the south. However, the speed at the latitude of maximum 200-mb. wind was weaker during May than April.

Changes in character of the hemispheric wind belts from April to May are also well portrayed in terms of the stand-

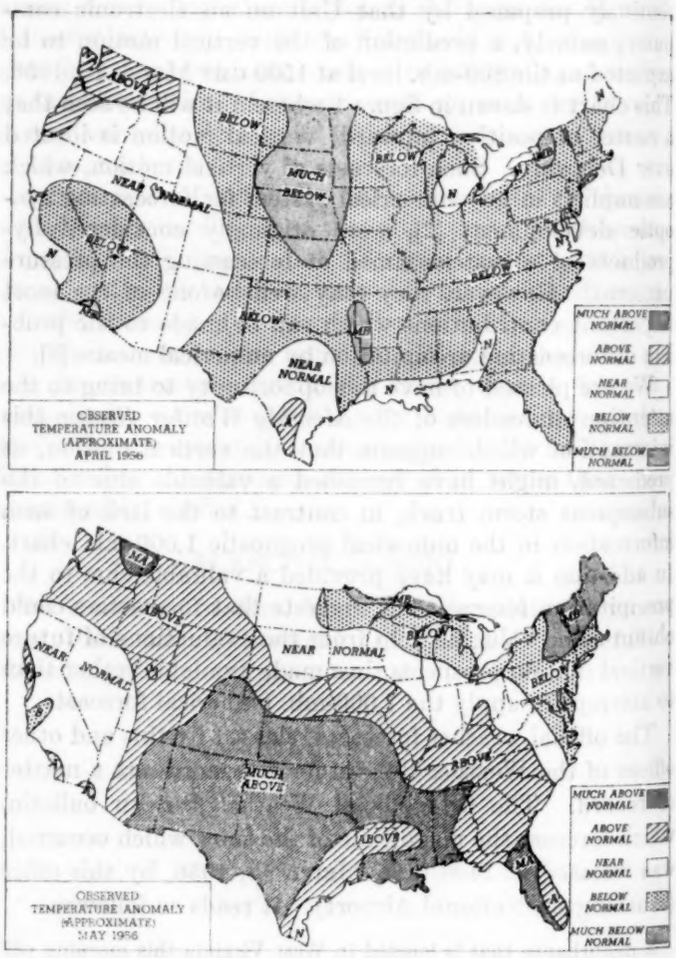

FIGURE 1.—Monthly mean surface temperature anomalies for (A) April 1956, (B) May 1956. The classes above, below, and near normal occur on the average one-fourth of the time; much below and much above each normally occur one-eighth of the time. Note marked warming from April to May in all parts of the country except extreme Southwest and Northeast.

[1] See charts I–XV following page 205 for analyzed climatological data for the month.

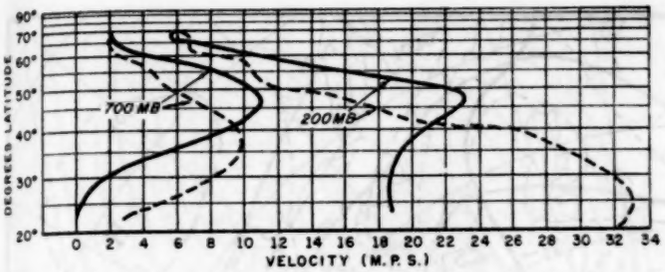

FIGURE 2.—Monthly mean zonal wind speed profiles for the Western Hemisphere at 700 mb. and 200 mb. for April (dashed) and May (solid) 1956. At both levels the latitude of maximum west wind shifted sharply northward from April to May.

ard fixed-latitude indices [5]. Table 1 gives monthly mean values of these indices at the 700-mb. level. Both temperate (or zonal) and polar westerlies increased in value from April to May this year, contrary to the normal seasonal trend which calls for a decline. Conversely, the subtropical westerlies weakened much more than normal, going from above normal values during April to below normal in May. All of these changes reflect the marked northward shift of the westerlies noted in figure 2. They indicate that whereas April was a classic low (zonal) index month with an expanded circumpolar vortex, May was just the opposite; namely, a high index month with a contracted circumpolar vortex [5].

REGIONAL

Changes in the general circulation on a regional basis are perhaps best illustrated by figure 3, the anomalous 700-mb. height change from April to May. This chart was prepared by subtracting the 700-mb. height departure from normal observed last month (fig. 1 of [3]) from its counterpart for this month, reproduced in figure 4. The largest anomalous height change in figure 3 is the fall of 590 feet near Baffin Bay, where a persistent blocking ridge during April [3] was replaced by an abnormally deep cyclonic vortex in May (fig. 4). A similar fall took place near Iceland, where a mean 700-mb. height anomaly of −330 feet was the largest departure from normal observed anywhere in the Northern Hemisphere during May (fig. 4). As frequently happens [5], these height falls in the subpolar region were accompanied by rises in the subtropics. In fact, a continuous band of anomalous height rises (fig. 3) and above normal heights (fig. 4) extended across middle latitudes from Japan eastward to Europe,

TABLE 1.—*Monthly mean values of standard indices of the 700-mb. westerlies in the Western Hemisphere during April and May 1956 (in meters per second).*

Index	Latitude belt	Month	Observed	Normal	Anomaly
Polar	55° N.–70° N.	April	2.6	3.7	−1.1
		May	3.2	1.9	+1.3
Temperate	35° N.–55° N.	April	7.5	8.3	−0.8
		May	9.7	7.7	+2.0
Subtropical	20° N.–35° N.	April	6.4	5.8	+0.6
		May	1.6	4.1	−2.5

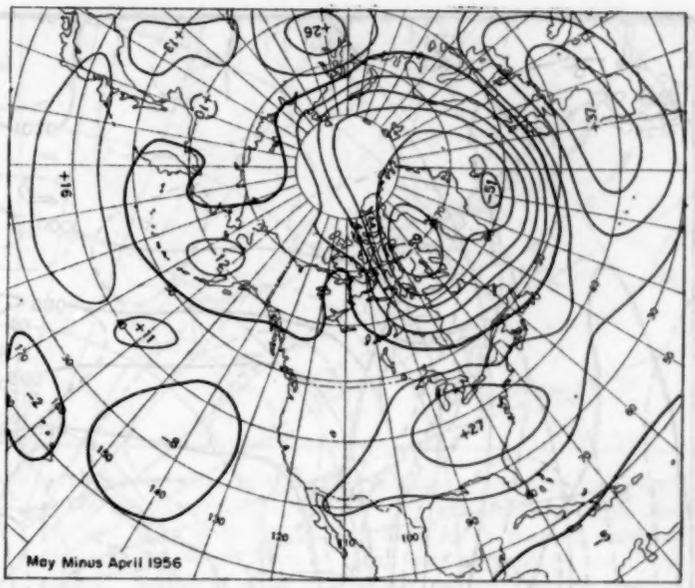

FIGURE 3.—Difference between monthly mean 700-mb. height anomaly for April and May 1956 (in tens of feet). Large anomalous height changes in eastern North America and Atlantic were indicative of marked acceleration and northward displacement of main belt of westerlies from April to May.

with largest rises in Europe and the eastern United States. The resultant acceleration of the westerlies north of 40° N., and their deceleration to the south, were most marked in the Atlantic and eastern North America, but also evident in the Pacific (fig. 3).

The geographical distribution of the field of mean horizontal geostrophic wind speed at the 700-mb. level and its departure from the May normal are illustrated in figure 5. Confluence of two branches of the 700-mb. jet stream over Japan produced a strong single jet downstream in the Pacific, with maximum speed of 20 m. p. s. (fig. 5A), 10 m. p. s. greater than normal (fig. 5B), just south of the Aleutians. The jet stream was weak and split into several branches over western North America; but from the Great Lakes northeastward to Scandinavia it was well defined and stronger than normal, by as much as 11 m. p. s. in the eastern Atlantic.

The 700-mb. jet streams drawn in figure 5A have been reproduced as solid curves in figure 6 for ready comparisons with their counterparts of April, drawn as dashed curves. It can be seen that the axis of the principal west-to-east jet was displaced about 5° of latitude northward in the United States from April to May. This northward shift was even more pronounced at the 200-mb. level, where strong mean jets were clearly delineated along the Gulf Coast in April (dashed) and over the Great Lakes in May (solid).

Northward displacement of the jet stream from April to May was accompanied by corresponding shifts of other features of the general circulation. For example, the principal track of sea level cyclones in the United States shifted northward during the month from a position

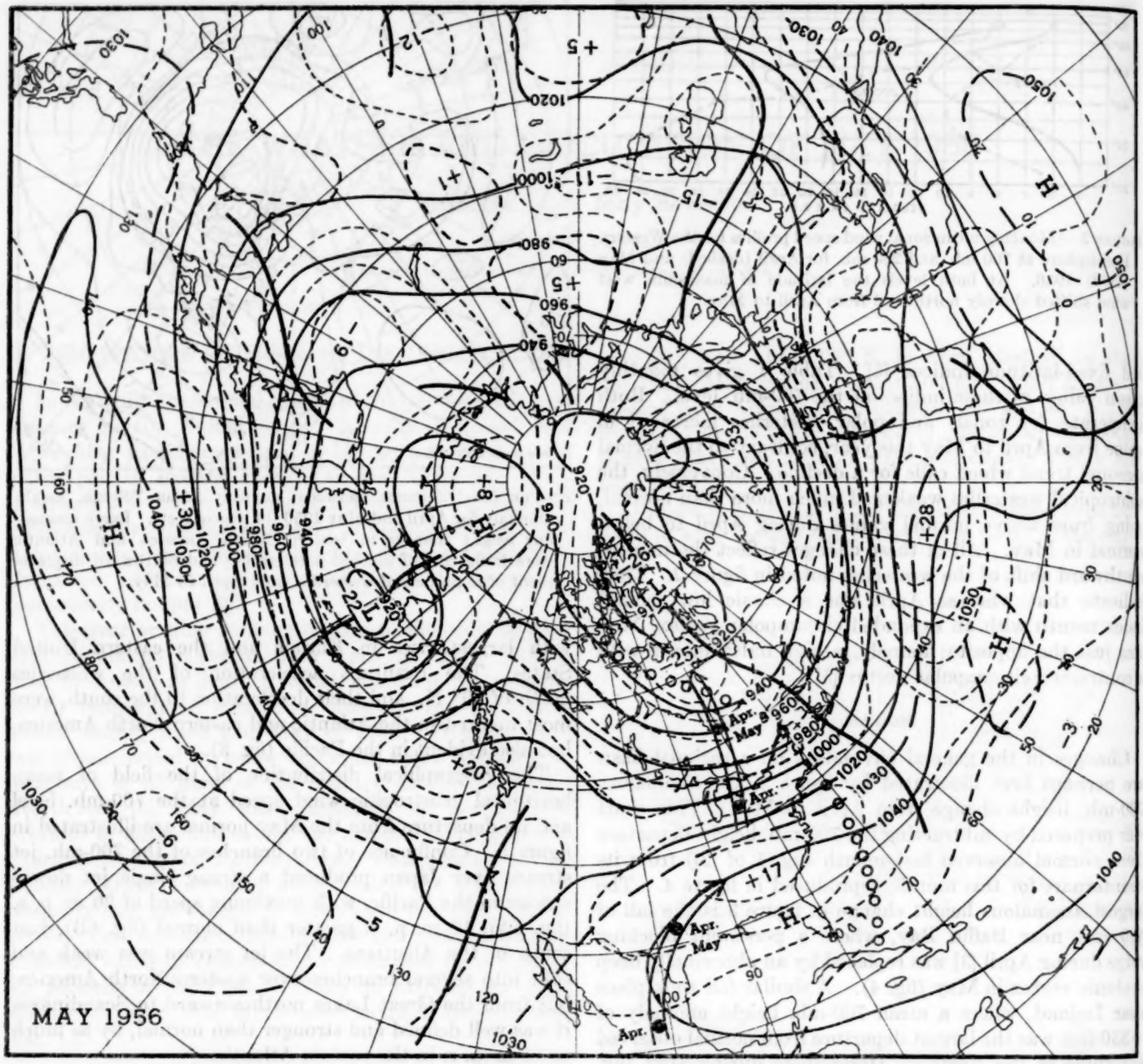

FIGURE 4.—Monthly mean 700-mb. height contours and departures from normal (both in tens of feet) for May 1956. Trough (heavy solid line) extending southward from Baffin Bay to Bermuda was east of its April position (line of open circles) at all latitudes. Centers of positive anomaly over Tennessee (+170 ft.) and negative anomaly over Hudson Bay (−250 ft.) moved northward from their April locations along tracks denoted by open arrows.

through the Ohio Valley in April, shown by the dashed arrow in figure 7A, to a position through the Upper Lakes in May, shown by a solid arrow. Each of these positions was a few degrees north of the 700-mb. jet stream for the appropriate month (fig. 6).

A similar northward displacement was experienced by the two largest centers of mean 700-mb. height departure from normal over the United States during April and May. The trajectories of these two anomaly centers are given by the open arrows of figure 4. The positive center moved northward from Mexico in April, to Texas during mid-April to mid-May, and then northeastward to Tennessee in May. The negative center was located over the Great Lakes in April, James Bay in mid-April to mid-May, and Hudson Bay in May. Thus a negative anomaly center over the eastern United States in April was replaced by a positive center in May, resulting in an anomalous height change of +270 ft. in figure 3.

In addition to the northward shift described above, a significant eastward displacement of several circulation

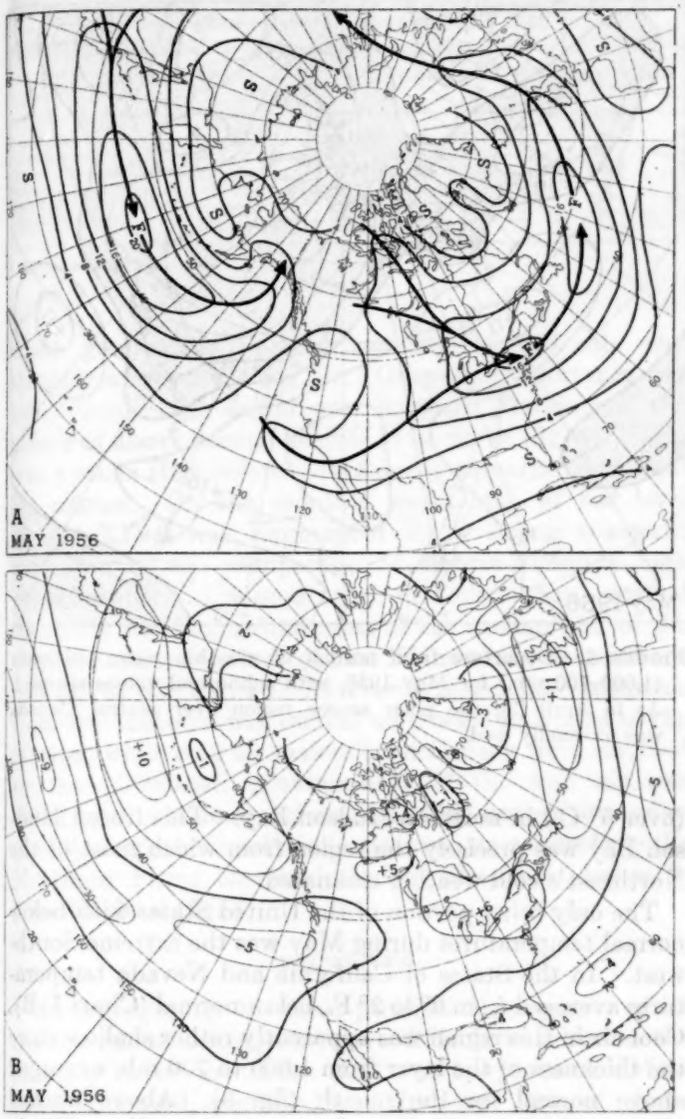

FIGURE 5.—(A) Mean 700-mb. isotachs and (B) departure from normal wind speed (both in meters per second) for May 1956. Solid arrows in (A) indicate axis of the mean jet stream at the 700-mb. level. Note center of fast wind speed (F) in the Northeast, where speeds were 6 m. p. s. above normal, and centers of slow speed (S) in Southeast and Northwest, where speeds were 4 meters per second below normal.

features occurred from April to May. Figure 4 contains the April position of the minimum-latitude trough in eastern North America (line of open circles). Comparison with the May position (solid line) indicates that this trough moved eastward at all latitudes from 20° to 80° N. A similar eastward shift took place in the principal track of sea level polar anticyclones from the Arctic Ocean and Canada into the northern United States. This track is shown in figure 7B by solid arrows for May and by dashed arrows for April. During both months the High track was extremely well marked and located almost directly beneath an axis of the 700-mb. jet stream. This meridional branch of the jet was well delineated and stronger than normal, as illustrated in figure 5 for May. Figure 6

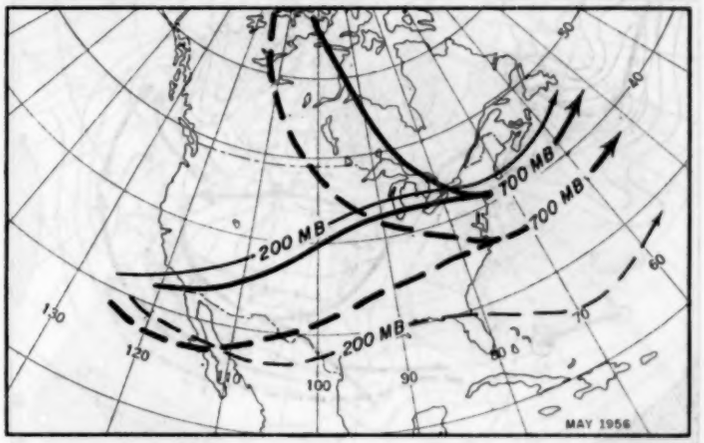

FIGURE 6.—Location of axes of jet streams on monthly mean charts at 700 mb. (heavy lines) and 200 mb. (thin lines) for April (dashed) and May (solid) 1956. At both levels marked northward displacement from April to May was evident in the United States. Eastward shift of 700-mb. jet in Canada was also important.

shows that the eastward displacement of this portion of the jet stream from April to May was just as well marked as the corresponding displacement of the primary anticyclone track (fig. 7B) and the monthly mean trough (fig. 4).

3. WEATHER OF THE MONTH

TEMPERATURE

Average temperatures during May were below normal northeast of a line extending approximately from Wilmington, N. C., through Milwaukee, Wis., to Havre, Mont. (Chart I–B). Largest departures from normal, in excess of 4° F., were recorded in New England, New York, and northeastern Minnesota. It was the coldest May on record at Caribou, Maine and the coldest since 1917 at many other stations in the Northeast. On the 9th, the following minimum temperatures (in °F.) were the lowest ever recorded in May: Portland, 23; Albany, 27; Hartford, 28; Providence, 29; and Norfolk, 36. In addition many new minimum records for individual dates were set during the month, but these are too numerous to mention here. Damage to crops by killing frost was severe and widespread, and many stations reported their latest freeze on record on the 25th. Further details are contained in an article by Lautzenheiser [6].

Cold air in the Northeast may be related to several features of the general circulation. Figure 4 shows that the region was dominated by stronger than normal northwesterly flow at the 700-mb. level. This flow had an extremely long fetch from western Canada and the Arctic Ocean to the north. Along its axis, delineated by the solid jet stream arrow in figure 5A, wind speeds averaged about 4 m. p. s. greater than normal (fig. 5B). It was instrumental in steering a large number of continental polar anticyclones at sea level from Canada and the Arctic

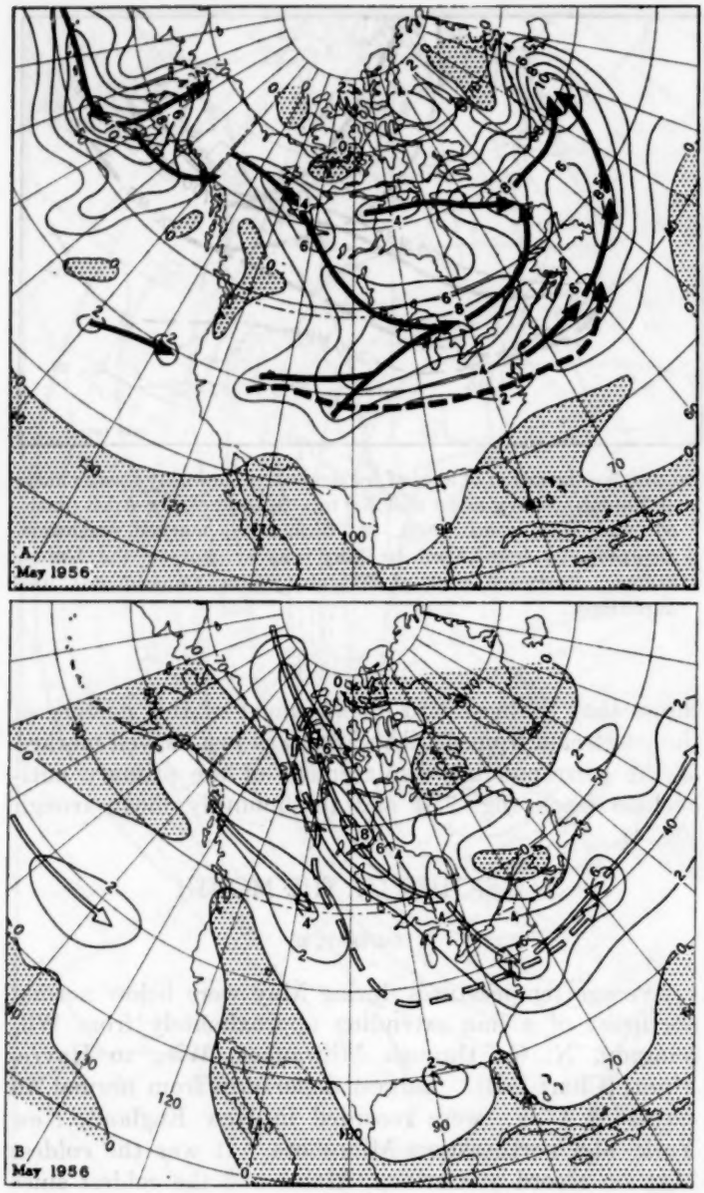

FIGURE 7.—Frequency of (A) cyclone and (B) anticyclone passages (within 5° squares at 45° N.) during May 1956. Principal cyclone tracks are indicated by solid arrows and anticyclone tracks by open arrows, with corresponding positions during April 1956, dashed. Note northward shift of cyclone track in United States April to May and eastward displacement of track of polar anticyclones.

into the northeastern United States. Their tracks are given individually in Chart IX and summarized in figure 7B. The passage of each of these Highs was responsible for a fresh outbreak of cold air in northern and eastern sections of the United States. The source region for this air is normally very cold, but this year it was much colder than normal. This is shown by figure 8, which gives the mean departure from normal of thickness in the layer between 1,000 and 700 mb. observed during May 1956. Temperatures averaged below normal in nearly all parts of Canada and the Arctic Ocean, with the greatest departures

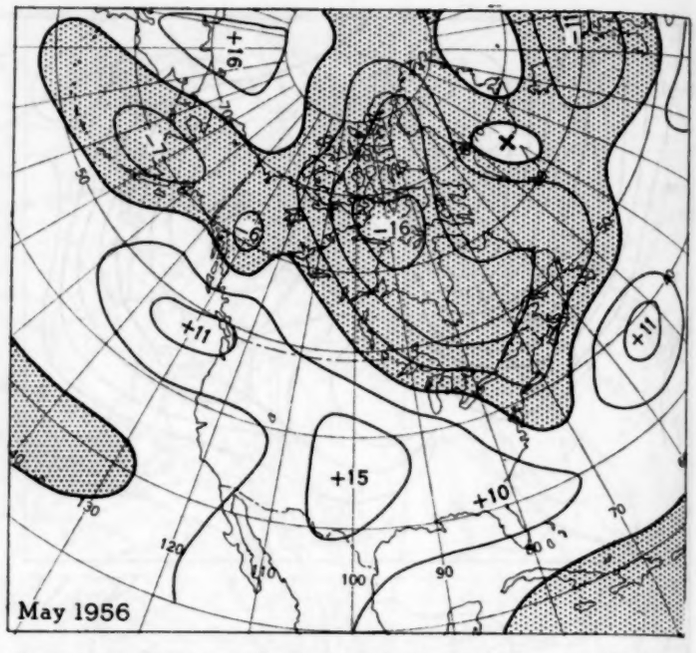

FIGURE 8.—Departure from normal of monthly mean thickness (1,000–700 mb.) for May 1956, with subnormal values stippled. As in April [3], the polar source region over central Canada was unusually cold.

(over 5° C.) in northern Hudson Bay. This frozen Hudson Bay was precisely the region from which most of the Northeast's cold weather emanated.

The only other portion of the United States with below normal temperatures during May was the extreme Southwest. In the States of California and Nevada temperatures averaged from 0° to 2° F., below normal (Chart I–B). Cool air in this region was apparently rather shallow since the thickness of the layer from 1,000 to 700 mb. averaged above normal for the month (fig. 8). Above normal cloudiness (Chart VI–B) and precipitation (Chart III) in the monthly mean trough (fig. 4) diminished sunshine (Chart VII) and solar radiation (Chart VIII) and kept surface temperatures low. In addition, some cool Pacific air was carried into the Southwest by a somewhat stronger than normal jet stream at the 700-mb. level (fig. 5).

In the remainder of the United States average temperatures for May were above normal (Chart I–B). Largest departures, over 6° F., were observed in the vicinity of the Texas–Oklahoma Panhandle, but departures in excess of 2° F. were recorded over a wide and continuous belt from Key West in the extreme Southeast to Seattle in the far Northwest. This was the warmest May on record at Dodge City, Kans., and Dallas, Fort Worth, and Wichita Falls, Tex. Throughout the country, many new records, too numerous to mention, were set for maximum temperatures on individual dates. A few of these were absolute maxima for May, and these are listed in table 2.

This abnormal warmth was directly related to the monthly mean circulation. Throughout the area of above normal temperatures both 700-mb. heights (fig. 4) and 1,000–700-mb. thicknesses (fig. 8) averaged above normal,

TABLE 2.—*Maximum temperatures during May 1956 which equaled or exceeded highest recorded on any previous May day*

Station	State	Temperature (° F.)	Date
Los Angeles	California	97	16
Albuquerque	New Mexico	*97	31
Grand Junction	Colorado	95	31
Salem	Oregon	95	17
Salt Lake City	Utah	*93	31
Olympia	Washington	92	30

*Equaled previous record.

while geostrophic relative vorticity at 700 mb. was strongly anticyclonic (fig. 9). Of special importance was the 700-mb. high center over northern Florida and the center of above normal heights to its north (fig. 4). This was a warm High composed primarily of maritime tropical air masses. On the monthly mean map at sea level (Chart XI) it was represented by a strong westward extension of the semipermanent Azores-Bermuda high pressure belt. Consequently, stronger than normal southerly flow dominated most of the eastern half of the United States at sea level (Chart XI inset) and the southern half at 700 mb. (fig. 4). As a result of this flow, warm air from low latitudes was carried northward into most of the Nation, while cold air masses from Canada were confined to the Northeast. Containment of the cold air was aided by the existence of stronger than normal westerlies (fig. 5) in a pronounced confluence zone stretching from the Northern Plains eastward through the Great Lakes to New England (fig. 4).

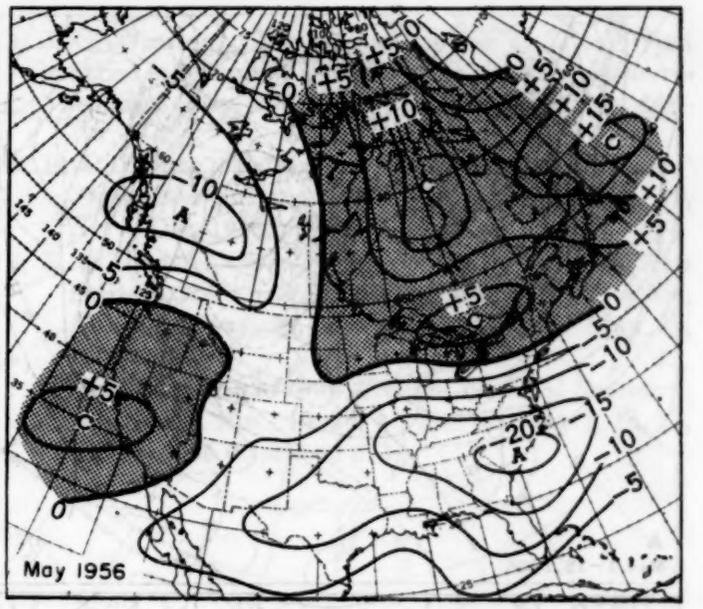

FIGURE 9.—Vertical component of the mean geostrophic vorticity at 700 mb. for May 1956, in units of 10^{-6} sec. $^{-1}$. Cyclonic vorticity and anticyclonic vorticity are considered positive and negative, respectively, and labeled C and A at centers. Anticyclonic vorticity dominated all parts of the United States except the Southwest and Northeast.

PRECIPITATION

As is frequently the case, precipitation, because of its discontinuous nature, was more difficult to relate to the monthly mean circulation than was temperature. Most straightforward, perhaps, was the large area of above normal precipitation observed in the Far West (Chart III). More than twice the normal amount for May fell in parts of California, Oregon, Idaho, and Nevada. This was the wettest May on record at Red Bluff, Calif., and Meacham, Oreg., and the second wettest at Blue Canyon, Calif. This precipitation was associated with a mean trough through the area at all levels of the troposphere (Charts XI to XV) and marked cyclonic relative vorticity at 700 mb. (fig. 9). Heavy rains combined with rapid snowmelt due to above normal temperatures produced flooding in sections of Idaho, Washington, Montana, and Oregon during the last week of May and first week of June. The worst flood on record occurred on the Kootenai River in Idaho, while lesser floods were reported on the Snake and Columbia Rivers.

Another band of plentiful precipitation stretched across the northern portion of the country from the Continental Divide eastward to New England, with heaviest amounts in the Northern Rocky Mountain States and the Great Lakes region. Akron, Ohio, reported a total of 9.60 inches for its wettest May in 70 years, while it was the 2d wettest May on record at Grand Rapids, Mich. Muskegon, Mich., had 12 thunderstorm days, the most ever observed in May. Much of this precipitation fell in an area of confluence (fig. 4) and cyclonic vorticity (fig. 9) at 700 mb., above a trough at sea level (Chart XI), and underneath a pronounced upper level jet (fig. 6). It was primarily cyclonic and frontal in nature as an unusually large number of closed Lows (as many as 9 per 5° box) traversed the Great Lakes region during the month (Chart X and fig. 7A).[2] Some of these cyclones were responsible for severe weather in the Midwest on several days of the month. Highlights included tornadoes in Michigan and Ohio, floods in Indiana and Missouri, high winds in Iowa, and hail in Nebraska and Wyoming. Part of the precipitation in the northern border States was in the form of snow and freezing rain since temperatures were below normal in this area. As much as 9 inches of snow fell at Wausau, Wis., on the 6th, and Harrisburg, Pa., reported its latest snow on record on the 16th.

In the remainder of the Nation near to below normal precipitation was observed during May, except for scattered heavy showers of the summer type along the Gulf and South Atlantic coasts and in Oklahoma. Chart III shows that less than half of the normal precipitation fell in parts of the Southwest, Southeast, and Central Plains. This was the driest May on record at Concordia, Kans., with total rainfall amount 0.99 inch, and at Del Rio, Tex., with a total of only 0.03 inch. It was the third driest May at Macon, Ga., and the eighth consecutive

[2] For a detailed analysis of the precipitation accompanying one of these storms, see adjoining article by Oliver and Shaw.

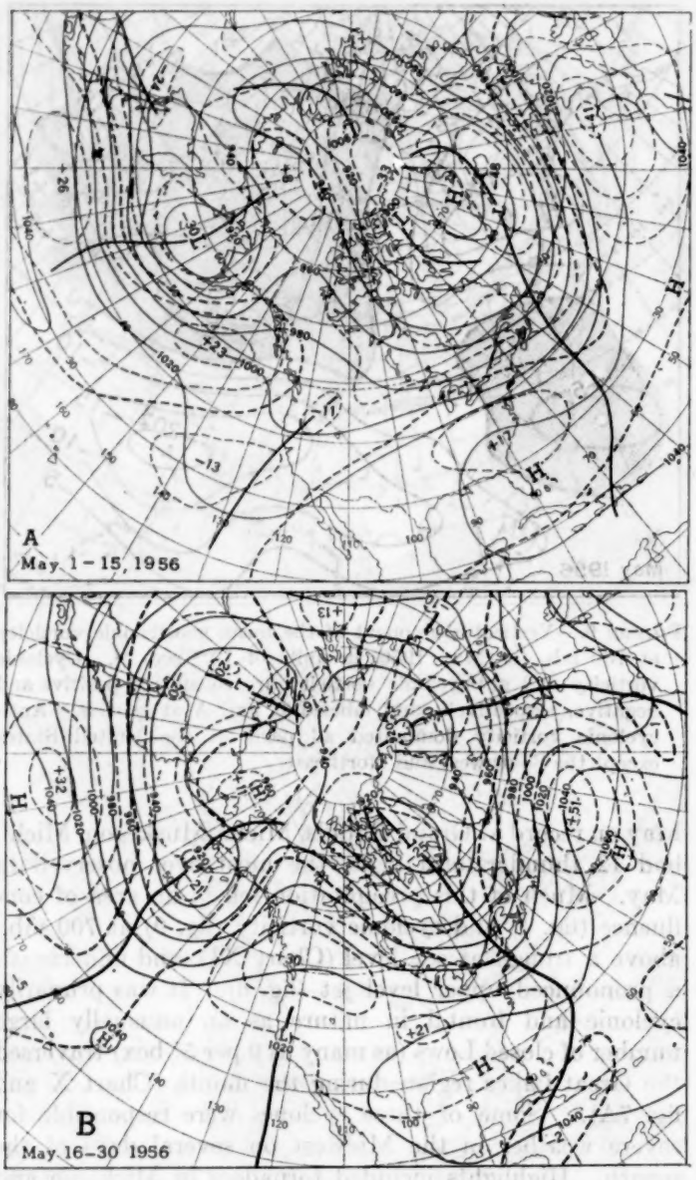

FIGURE 10.—Fifteen-day mean 700-mb. height contours and departures from normal (both in tens of feet) for (A) May 1–15, 1956, and (B) May 16–30, 1956. Note cutting off and weakening of west coast trough during second half of month as deep trough developed in eastern Pacific.

month with below normal precipitation at Des Moines, Iowa, and Wichita, Kans. This extensive dry weather in the United States occurred underneath pronounced anticyclonic circulation aloft. Figure 4 shows above normal 700-mb. heights in most of the country with two intense centers of positive anomaly, one over Tennessee and the other off the northwest coast. The marked anticyclonic vorticity associated with these centers is well portrayed in figure 9. In the Southeast strong anticyclonic shear south of the jet stream over the Great Lakes (fig. 5) combined with sharp anticyclonic curvature around the high center in Florida (fig. 4) to produce a center of intense anticyclonic vorticity over South Carolina. The desiccative effect of subsidence in regions of anticyclonic vorticity, particularly during the warm season, has frequently been noted.

TABLE 3.—*New daily temperature records established during May 1956 at cities with extremes for both maximum and minimum readings*

City	State	Maximum temperature (° F.)	Date	Minimum temperature (° F.)	Date
Alpena	Michigan	81	11	30	26
Baltimore	Maryland	94	14	41	17
Charlotte	North Carolina	95	14	44	17
Nantucket	Massachusetts	76	13	37	28
Newark	New Jersey	92	13	42	28
Philadelphia	Pennsylvania	92	14	37	17
Providence	Rhode Island	88	13	35	17
Richmond	Virginia	94	13	41	26
Wilmington	Delaware	93	14	35	17

4. TRANSITION WITHIN THE MONTH

The general circulation during May 1956 was composed of two differing regimes. These are portrayed in figure 10, which shows 15-day mean 700-mb. maps for the two halves of the month. During the first half (fig. 10A), the basic pattern in the United States consisted of a deeper than normal trough along the west coast and stronger than normal ridge near the Appalachians. As a result, temperatures were cold in the Far West, but warm in the remainder of the country (except the Northeast). During the week ending May 13, surface temperatures averaged 10° below normal in Nevada, but 12° above normal in Kansas [7].

An interesting transition occurred in the second half of the month (fig. 10B). The trough which had been in the central Pacific (fig. 10A) moved eastward from about 180° to 160° W., intensified at middle latitudes, and extended its influence to low latitudes. Consequently, the trough along the west coast of the United States was bypassed by the main belt of westerlies and converted into a weak low-latitude feature, while heights rose to above normal levels throughout the western United States. At the same time, a trough in the western Atlantic retrograded to eastern North America, a strong ridge developed in mid-Atlantic, and a deep trough appeared along the European coast (fig. 10B). As a result of these circulation changes, surface temperatures averaged above normal during the second half of the month in the western two-thirds of the United States, but below normal in the East. Maximum departures of +9° F., in the Northwest and −9° F., in the Northeast were observed for the weeks ending May 20 and 27 [7].

One manifestation of this transition is the odd circumstance that several cities in the eastern United States experienced record-breaking temperatures for both maximum and minimum readings within the same month. Some of these new records, which are for individual dates only, are listed in table 3. Note that the maximum temperatures occurred during the first half of the month; the minimum temperatures during the second half. In some cases these opposite extremes were recorded only 3 days apart.

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HEAVY WARM-SECTOR RAINS FROM ILLINOIS TO MIDDLE ATLANTIC COAST, MAY 26–28, 1956

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1. INTRODUCTION

During the weekend of May 26–28, 1956, a large, cold, high pressure system moved slowly off the east coast of the United States followed by a broad current of moist tropical air from the Gulf of Mexico. As this moist current overran the retreating cold air mass, widespread warm-frontal-type rains spread over the northeastern United States. The warm front was poorly defined at the surface, with a broad zone of gradual transition. Aloft the front was somewhat more distinct but still quite broad. To the rear of this frontal zone the warm sector air mass extended uninterruptedly to the Gulf of Mexico. The synoptic situation on May 27 is presented in figure 1A.

It was in the extensive belt of mT air that the rains described in this paper occurred. The rains began in Illinois early Saturday morning of May 26 and spread eastward with the warm front to the coast by Sunday morning. Surprisingly enough, however, they continued throughout a broad strip from central Illinois eastward all day Saturday, Sunday, and part of Monday. The rain over most of this area ceased when a southward-moving cold front brought dry air and subsiding currents to the region.

East of the Appalachian Mountains the warm-sector rains were accompanied by a deepening trough at the surface and aloft. Here the rains began when the flow at the 700-mb. level became cyclonic and ended when the warm-sector flow lost its cyclonic curvature after passage of the 700-mb. trough. The principles relating surface precipitation to cyclonic curvature aloft [1] have long been recognized so the rains occurring in this part of the country were not unusual. Development of heavy rains which fell farther to the west in the warm sector were not so easily explained.

The upward motion in the warm sector must have been quite widespread to produce such a large area of precipitation and therefore should be subject to detection or computation by several of the methods which have been developed for the study of vertical motions. The cause and distribution of these vertical motions will be investigated in this paper by examination of each of the following types of charts: 1. precipitable moisture, 2. Showalter stability index, 3. differential advection, 4. surface isobaric convergence, 5. sea level pressure change (Laplacian of), 6. curvature of flow pattern at 700 mb. and higher, 7. jet stream, 8. tropopause, and 9. JNWP vertical motion computations (900–400 mb.).

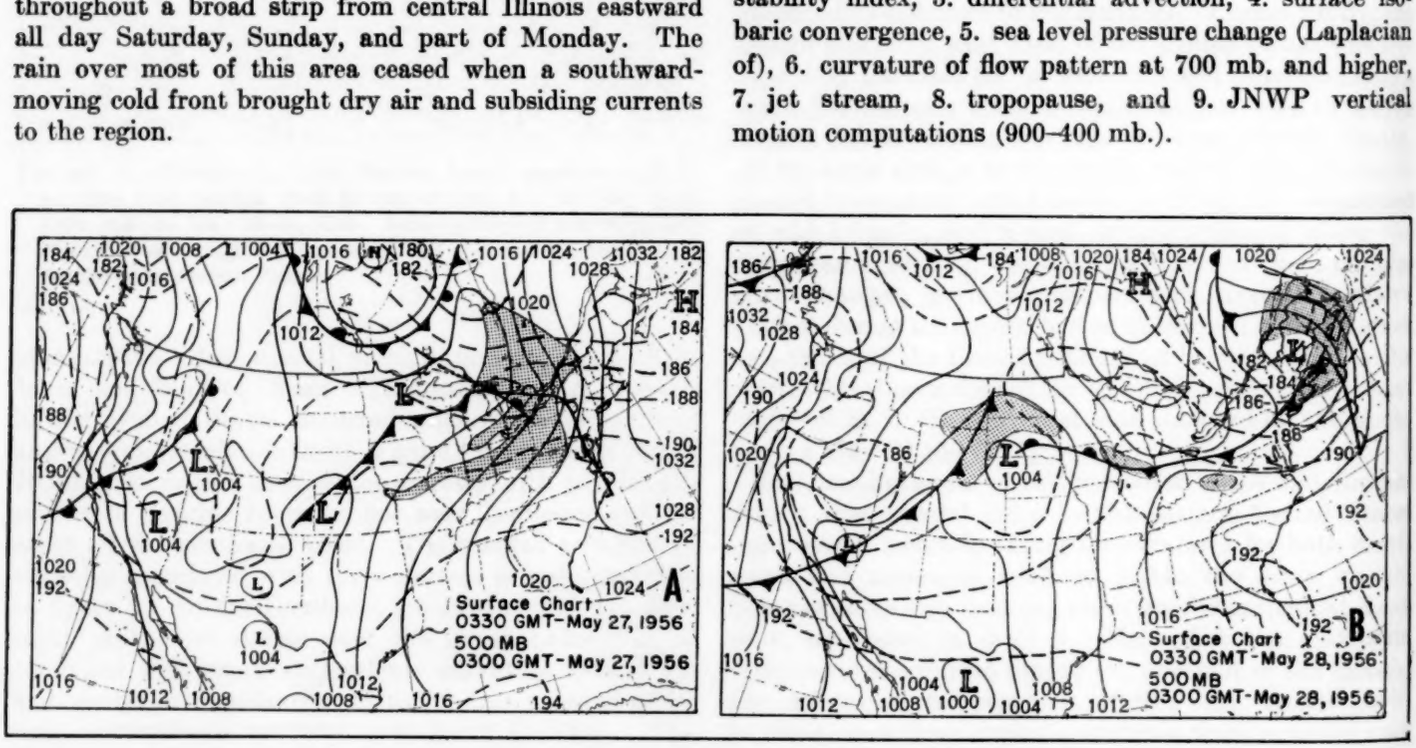

FIGURE 1.—Surface charts for 0330 GMT with 500-mb. contours for 0300 GMT superposed: (A) May 27, (B) May 28, 1956. Solid lines are sea level isobars; dashed lines are 500-mb. contours; shaded area indicates current precipitation.

2. PRECIPITABLE MOISTURE

In the analysis of the moisture content and distribution within the warm mT air mass, two methods were employed. Charts were prepared showing the total amount of precipitable water available (fig. 2), and values of the temperature minus dew point at the 850- and 700-mb. levels (not shown) were checked. Both methods showed an abundance of precipitable water in the warm air mass whose source region was the Gulf of Mexico. Moreover, the surface had been saturated by widespread rains which fell through most of the central and southern Plains during the 3-day period prior to May 27. Dew points at the surface (fig. 5A) at 0300 GMT on May 27 were in the 60's as far north as the Great Lakes region.

Precipitable water amounts were computed to show the available moisture between the surface and the 400-mb. level using methods developed by Solot [2] and Showalter [3, 4]. These values were computed for all available radiosonde stations in the central and eastern United States for 12-hour intervals between 1500 GMT May 26 and 1500 GMT May 27. Nearly the entire eastern two-thirds of the Nation had precipitable water values in excess of 1 inch (fig. 2). The area of the warm sector rains was overrun by an air mass containing over 1½ inches of precipitable water. The maximum value computed was 2.21 in. at Rantoul, Ill., less than 30 miles from Farmer City, Ill., where 7 to 9 inches of rain fell during the following 9 hours.

3. STABILITY

There is no doubt as to the unstable character of the warm mT airmass in this case since showers and thunderstorms were numerous throughout the rain belt. In order to show more quantitatively the instability of the airmass and the distribution of stability, the Showalter Stability Index Charts [5] as prepared by the National Weather Analysis Center are presented in figure 3. Even a cursory examination of these charts shows the presence of a large unstable area which spread eastward from Missouri and Illinois at 0300 GMT on the 27th to include all of the area from Missouri to eastern Pennsylvania by 1500 GMT of the same day.

4. DIFFERENTIAL ADVECTION

The foregoing analyses of moisture and instability determined the presence of these two basic requirements for heavy precipitation over a much larger area than that in which precipitation actually occurred. In beginning our investigation of the third basic requirement, vertical motion, the principle of differential advection seemed a promising vehicle for the initial attack since it might explain why heavy sustained rains fell over Illinois, Indiana, and Ohio, and only scattered, comparatively light amounts of rainfall were reported from the adjacent States of Kentucky and Tennessee. Gilman's [6] concept of horizontal differential advection as a major cause of vertical motion has been tested with encouraging results in earlier studies of heavy rains by Erickson [7], Appleby [8], and Lott [9].

Prior to, and during the period under consideration, large-scale, warm-air advection was in progress from the Rockies eastward to the Appalachians and from the Gulf of Mexico northward to the Great Lakes. The thermal pattern was illustrated by preparation of thickness charts for the 1000–700-mb. layer (fig. 4). On these charts isotachs for maximum winds from the surface to 7,000 ft. m. s. l. were superimposed and a few representative winds plotted. The combined thickness and isotach

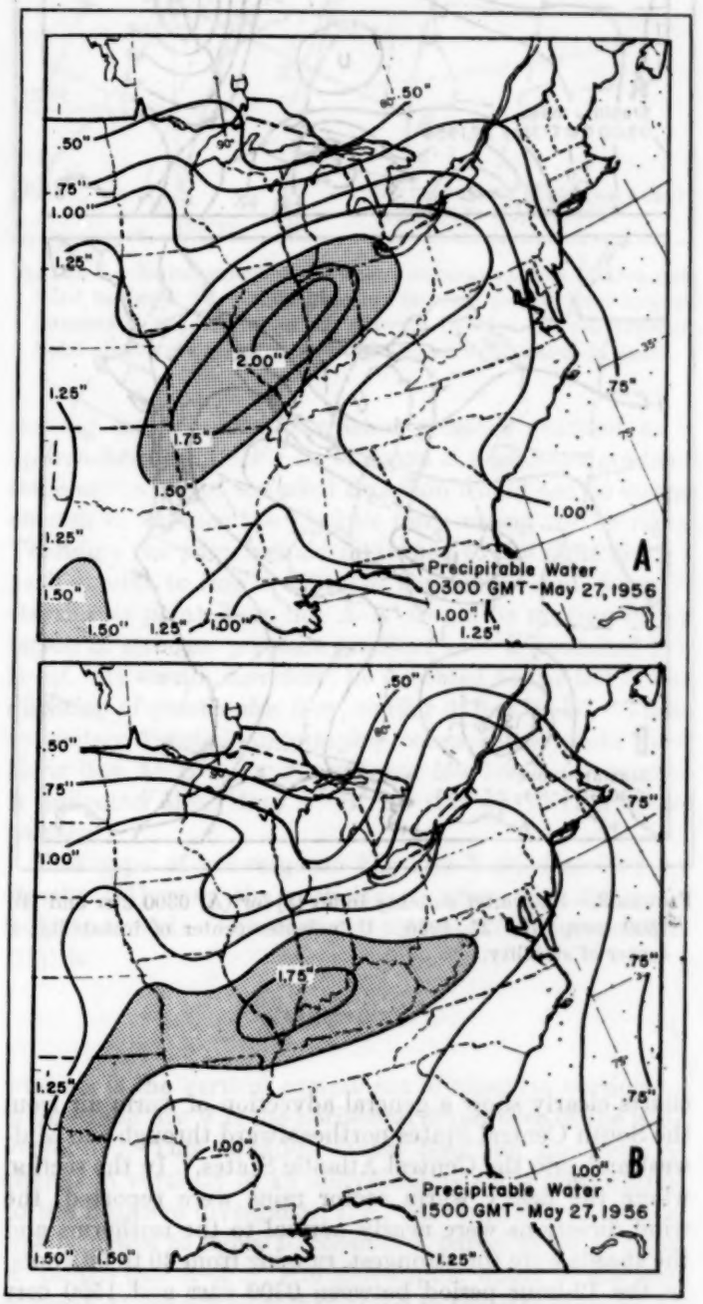

FIGURE 2.—Precipitable water (inches) for layer from surface to 400 mb. for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956.

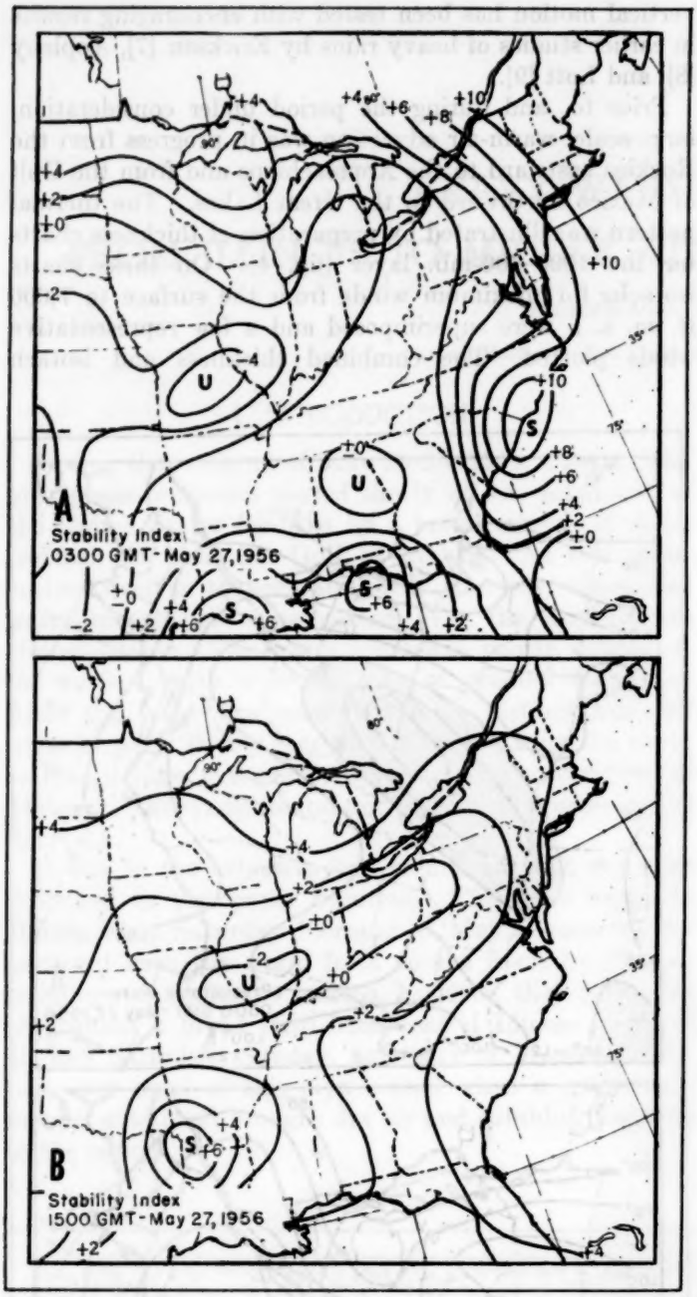

FIGURE 3.—Showalter stability index [5] for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956. U indicates center of instability, S center of stability.

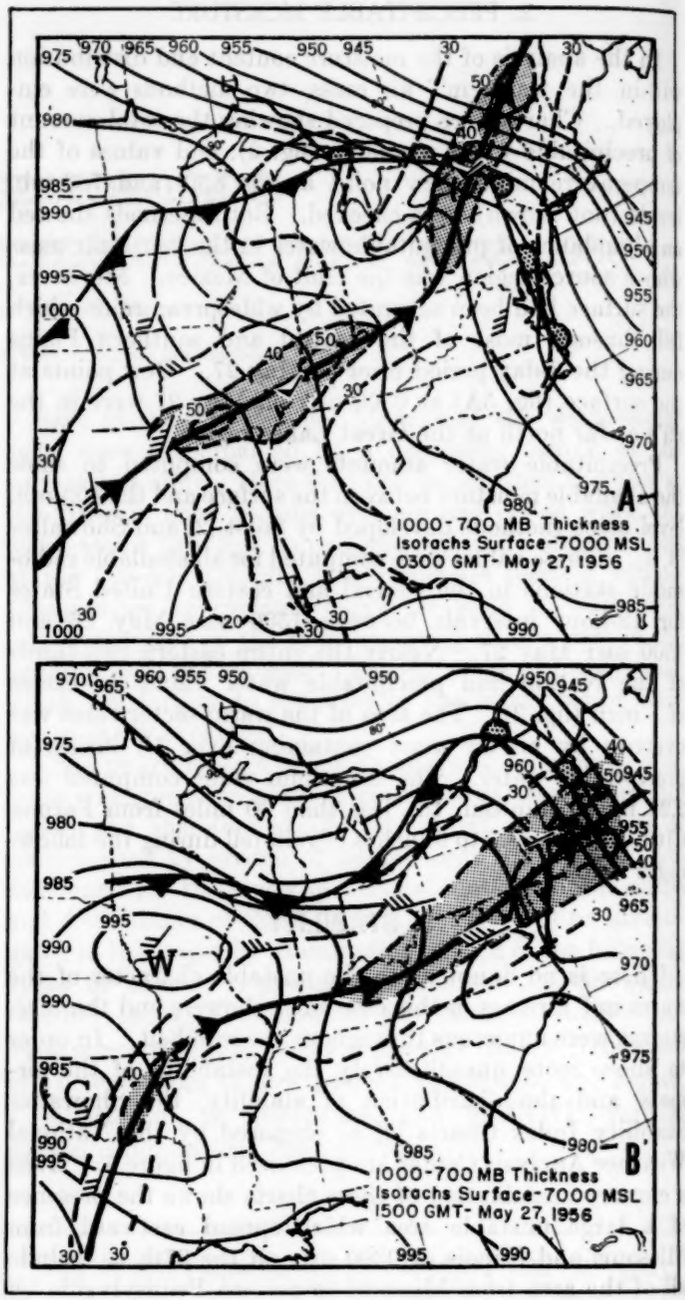

FIGURE 4.—1,000–700-mb. thickness charts with isotachs of maximum wind from surface to 7000 ft. superposed for (A) 0300 GMT and (B) 1500 GMT, May 27, 1956. Solid lines are 1,000–700-mb. thickness (hundreds of feet); dashed lines are isotachs (kt.) of maximum wind.

charts clearly show a general advection of warm air from the South Central States northeastward through the Midwest and into the Central Atlantic States. In the section where the heavy warm sector rains were reported, the wind directions were nearly normal to the isotherms and the speeds were the strongest, ranging from 30 to 50 knots. In the 12-hour period between 0300 GMT and 1500 GMT on the 27th, the thickness lines over the area of heaviest rains moved from 60 to 120 nautical miles at a speed of from 5 to 10 knots. The relatively large difference (25 to 40 knots) between the speed of the advective wind and the speed of movement of the thickness field gives an indication of the large amount of vertical motion which must have occurred in this area. In the adjacent areas the winds were more nearly parallel to the thickness lines and advection was further reduced by the lower speeds of the wind.

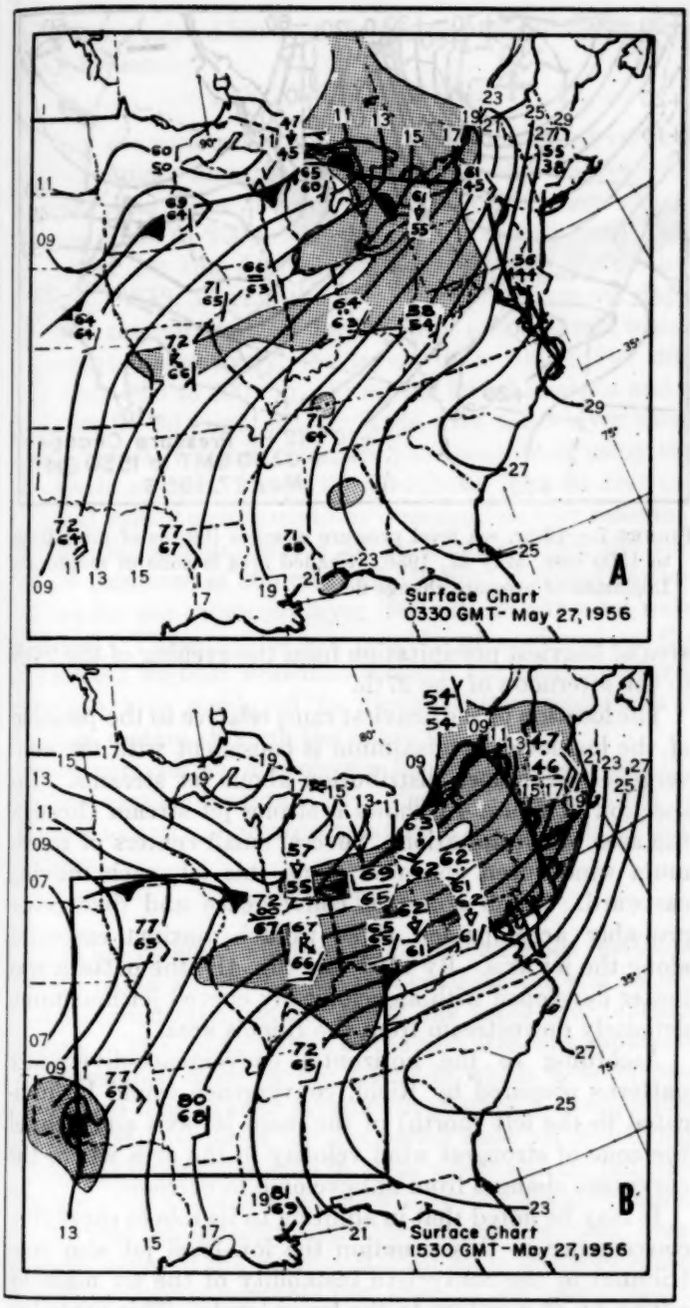

FIGURE 5.—Surface charts for (A) 0330 GMT and (B) 1530 GMT, May 27, 1956. Shaded area indicates current precipitation; representative reports are plotted. See figure 6 for enlargement of isobaric pattern of area outlined in (B).

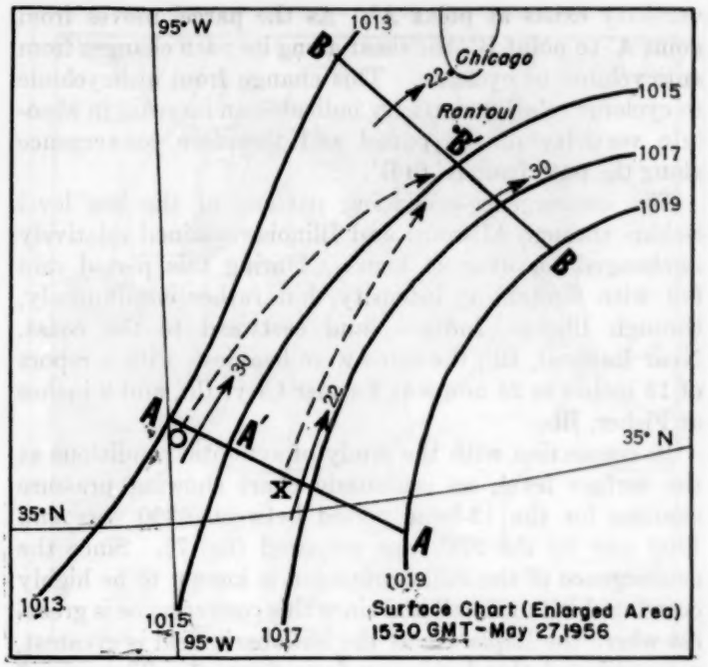

FIGURE 6.—Enlargement of pertinent isobaric pattern of area outlined in figure 5B. Solid lines are isobars; dashed lines are approximate trajectories of air parcels in area of convergence. Solid arrows are geostrophic wind vectors with speeds in knots.

5. SURFACE ISOBARIC CONVERGENCE

The sea-level isobaric pattern for 1530 GMT on May 27 (fig. 5) in the vicinity of Missouri and Illinois is a good example of Bjerknes' classical convergence pattern [10]. Figure 6 is an enlargement of the pertinent isobars within the box outlined in figure 5B. If we consider this isobaric pattern as stationary relative to the winds we see that a parcel of air located at point O on line A–A′ would be moving into an area of weaker pressure gradient as it approached line B–B′. In this area the pressure gradient force to the left of the wind direction would not be strong enough to balance the Coriolis force acting to the right. Therefore the parcel would be turned to the right along a path similar to line O–B′. On the other hand, a parcel starting at point X on line A–A′ would be moving into a region of stronger pressure gradient as it approached line B–B′. It would, therefore, be deflected to the left of the direction of geostrophic flow, similar to line X–B′. These oppositely directed ageostrophic components would meet along line A′–B′. In this manner low-level convergence is indicated along line A′–B′ by the sea level pressure pattern.

This type of convergence has also been described by Rossby [11] using the vorticity equation with the same isobaric model. The vorticity equation (see for example [12]) is

$$\frac{d\eta}{dt}=\eta(-\text{div } \mathbf{V}),$$

where η is the vertical component of absolute vorticity, t is time, and div $\mathbf{V}$ is the horizontal divergence of the wind vector $\mathbf{V}$. This equation states that the time rate of change in vorticity of an individual parcel is proportional to the negative divergence, i. e., convergence. Applying this principle to figure 6, consider a parcel of air at point A′ on the line A–A′. The geostrophic winds to the west of point A′ are stronger than those to the east of point A′. The resultant shear indicates that anticyclonic relative

vorticity exists at point A′. As the parcel moves from point A′ to point B′, the shear along its path changes from anticyclonic to cyclonic. This change from anticyclonic to cyclonic relative vorticity indicates an increase in absolute vorticity of the parcel and therefore convergence along the path from A′ to B′.

The convergence-producing pattern of the sea level isobars through Missouri and Illinois remained relatively unchanged for over 24 hours. During this period rain fell with fluctuating intensity, but rather continuously, through Illinois, Indiana, and eastward to the coast. Near Rantoul, Ill., the rains were heaviest, with a report of 13 inches in 24 hours at Farmer City, Ill., and 8 inches at Fisher, Ill.

In connection with the study of synoptic conditions at the surface level, an isallobaric chart showing pressure changes for the 12-hour period between 0300 GMT and 1500 GMT on the 27th was prepared (fig. 7). Since the convergence of the isallobaric wind is known to be highly correlated with rainfall and since this convergence is greatest where the Laplacian of the isallobaric field is greatest, we computed this Laplacian from figure 7. The axis of greater values is shaded and agrees well with the area of persistent warm-sector rainfall.

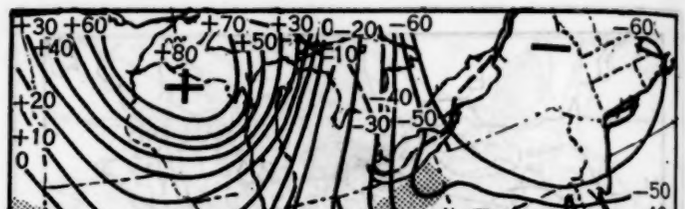

FIGURE 7.—12-hr. sea level pressure changes (tenths of mb.) 0330 to 1500 GMT, May 27, 1956. Shaded area is zone of maximum Laplacian of pressure change field.

6. JET STREAM ANALYSIS

Low-level convergence in an unstable airmass is usually associated with high-level divergence when large upward velocities are observed; Riehl [13] has described how the jet stream is associated with rainfall and just where high-level divergence would be found relative to the axis of the jet stream and the wind maxima along the jet. In this case, however, examination of the 300-, 200-, and 150-mb. isotach charts eliminated the upper-level jet as a contributing factor in the warm-sector precipitation.

On May 26 at 0300 GMT, the jet stream flowed southeastward from north of Lake Winnipeg to northern New Jersey. During the next 48 hours the jet moved slowly northward to a path from just west of Hudson Bay to northern New England. On the 28th a shorter secondary jet appeared at 200 mb. extending eastward from eastern Lake Superior to Delaware Bay. During the entire period under consideration the closest proximity of the upper jet stream to the area of heavy precipitation in the Midwest was several hundred miles. The precipitation area was under a region of light, variable, high-level winds. Thus it was apparent that the relationship of precipitation to jet stream position would not, in this case, be pertinent.

After abandoning the search for upper jets, attention was turned toward low-level jets. Here more gratifying results were obtained. All available wind reports were checked for maximum speeds between the surface and 7,000 ft. m. s. l. Isotachs prepared from these data revealed the presence of a well-defined, low-level jet running from Oklahoma northeastward into the Middle Atlantic States (fig. 4). This strong current persisted just south of the area of heaviest precipitation from the evening of the 26th to the afternoon of the 27th.

The location of the heaviest rains relative to the position of the low-level jet maximum is consistent with the convergence-divergence distribution about jet streams. Inspection of figure 4A shows a strong jet stream through the area of precipitation. Several small centers of maximum wind speed appeared along this jet, each moving eastward. Small zones of convergence and divergence probably accompanied these isotach maxima eastward along the jet axis. By 1500 GMT (fig. 4B) the pattern was better developed with a cyclonically curved jet maximum definitely downstream from the Illinois area.

According to the horizontal convergence-divergence patterns prepared by Riehl, convergence would be indicated to the left (north) of the main jet axis and behind the zone of strongest wind velocity in the area where the curvature changes from anticyclonic to cyclonic.

It may be noted that in addition to its role in supplying convergence in this situation the low-level jet also contributed to the convective instability of the air mass by advection of moisture to the lower levels. This contribution, it must be admitted, was probably of lesser value due to the presence of both instability and abundant moisture in the air mass prior to May 27.

Incidental to inspection of the high-level isotach charts the tropopause chart was examined to determine if there were any possible correlation between the tropopause "breaklines" and the precipitation areas. This investigation was stimulated by a recent study by Culkowski [14] of the tropopause analysis as related to surface forecasting. Culkowski's paper described the southern or eastern edges of a breakline as the optimum location for heavy precipitation but also pointed out the diminished value of tropopause breaks as indicators of precipitation areas during the summer months. In this case no apparent

correlation existed between the tropopause and the surface precipitation.

7. VERTICAL MOTION

After the various methods by which pronounced vertical motion might have been indicated in the warm-sector airmass had been investigated, vertical motion charts for the 900- to 400-mb. layer were prepared from data furnished by the Joint Numerical Weather Prediction Unit (JNWP). During the period, JNWP prepared daily vertical motion analyses for 800 mb. and 550 mb. which represent, respectively, the layers from 900 to 700 mb. and from 700 to 400 mb. From the initial analysis and a forecast for 30 minutes later made with the 3-layer baroclinic model, vertical velocities were computed using the adiabatic method. Both the 30-minute forecast and the vertical velocity computations were produced by machine. By simple addition of the values computed for the two layers (centered at 800 mb. and 550 mb.), vertical motion values for the combined layer (900 mb. to 400 mb.) were derived. These values are roughly proportional to the integrated vertical velocities through the combined layer and are here employed to illustrate the instantaneous vertical motion through the entire layer.

Superimposition of isohyets for 24-hour precipitation on the vertical motion charts (fig. 8) shows relation of rainfall to areas of greatest positive, i. e., upward, vertical motion.

8. CONCLUSIONS

The heavy and widespread warm-sector rains discussed in this paper were the result of a combination and an unusual concentration of several of the usual precipitation factors. The configuration of the rain area was apparently determined more by the extent to which these factors interacted than to their presence or absence. Precipitable water charts prepared for this period show an abundance of available moisture even in areas where no rain fell, and the area of instability as shown by the stability index charts was considerably larger than the precipitation area. A large share of the warm-sector air mass was very moist and convectively unstable just prior to the precipitation.

With two of the basic elements, i. e., moisture and instability, determined to be present in sufficient quantities, the third element, vertical motion, was investigated. Factors which are favorable for vertical motion—differential advection, low-level convergence, Laplacian of sea level pressure change, and the effects of the low-level jet—interacted in such a manner that the greatest concentration of vertical motion assumed a long narrow east-west orientation which coincided rather well with the observed pattern of heavy precipitation. Upper-air features such as position of the high-level jet, tropopause breaks, and cyclonic curvature aloft were notably absent during the period.

In summary, it is apparent that the heavy rains in the warm sector resulted from a strong sustained vertical motion through a very moist and convectively unstable air mass. The greatest rainfall amounts were reported from areas which coincided very well with zones of maximum effective low-level convergence and cyclonic vorticity.

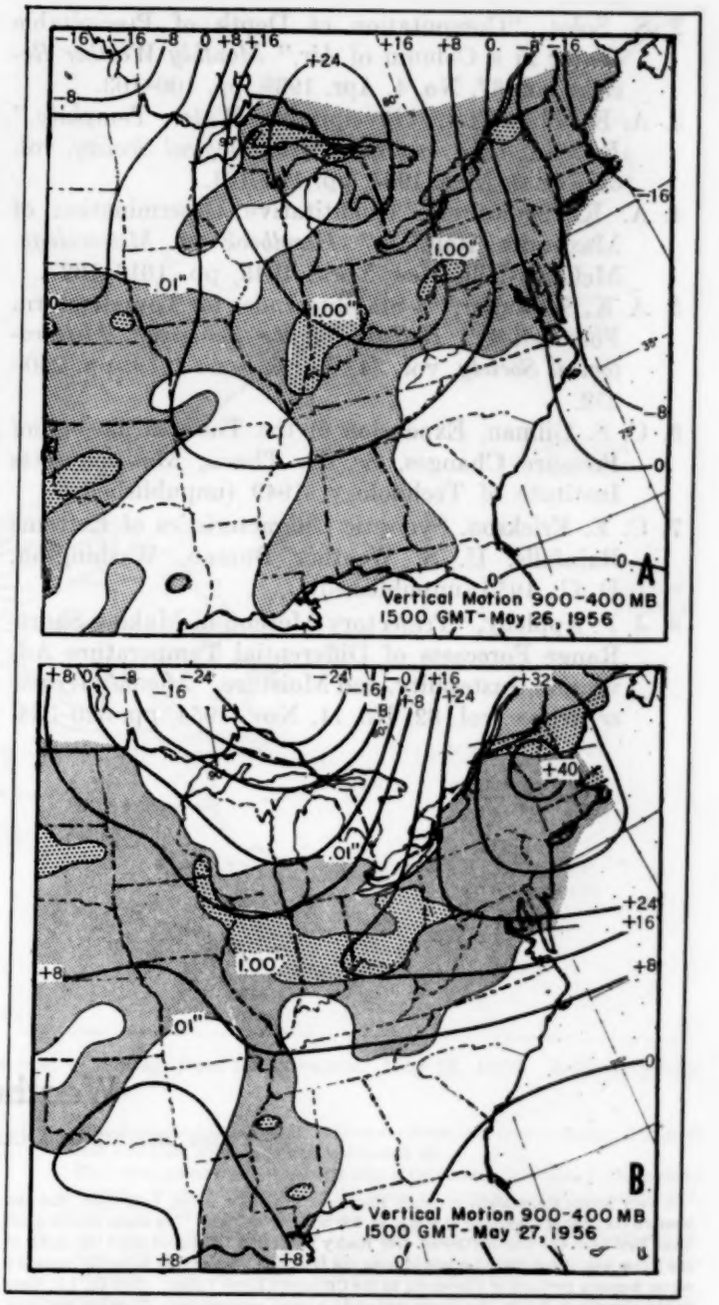

FIGURE 8.—Vertical motions (solid lines, mm.sec.$^{-1}$) for layer 900–400 mb. for 1500 GMT, (A) May 26 and (B) May 27, 1956. Fine-stippled area represents 24-hr. precipitation of 0.01 to 1.00 inch and coarse-stippled area 1.00 inch or more ending at 1230 GMT, (A) May 27 and (B) May 28, 1956.

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Weather Notes

SEVERE THUNDERSTORM, CLEVELAND, OHIO, MAY 12, 1956

A very severe thunderstorm struck the center of Rocky River, Lakewood, and the western portions of Cleveland at 8:45 p. m. EST on May 12, 1956. The storm moved in off Lake Erie from the west-northwest over Rocky River and Lakewood until the center of the storm was about 2½ miles inland from the lake, and then moved generally eastward across western portions of Cleveland to the Cuyahoga River Valley. (See fig. 1.) East of the Cuyahoga River, the storm moved in a more northeasterly direction but very little wind damage occurred.

In the path of the storm damage very little rain occurred, but the eastern portions of the city received a torrential downpour and hail up to 1 inch in diameter. Downtown Cleveland reported ½-inch hail. The heavy rainfall, particularly in Shaker Heights and Cleveland Heights, caused serious flooding of underpasses and low spots, and hundreds of basements. The Weather Bureau recording rain gage located at East 140th Street and the lakefront, recorded about 2 inches of precipitation in 30 minutes. Evidence indicates heavier amounts about 3 miles southeast of the Weather Bureau gage.

At the airport, 2¼ miles southwest of the southern edge of the path of damage, the maximum wind was 45 m. p. h. from the northwest, the fastest mile 57 m. p. h. from the northwest, and on the direct-reading indicators gusts to 71 m. p. h. were observed. On a privately owned anemometer located on Beach Road ("G" in fig. 1), gusts to 100 m. p. h. were observed on the indicator before the mast of the anemometer bent over, and the instrument ceased to function.

A pressure jump occurred at the airport at 8:45 p. m., EST amounting to 0.16 inch Hg in 3 minutes. The pressure fall in the 45 minutes preceding 8:45 p. m. amounted to 0.18 inch. On a privately owned Friez 4-day barograph located at 230 Buckingham Road, Rocky River, Ohio (just north of "C" in fig. 1), a fall of 0.32 inch Hg was recorded in the 45 minutes prior to the low point, and then a pressure jump of 0.22 inch Hg.

Seven people were killed and about 70 injured during the storm. Three of the deaths occurred when a tavern collapsed (point "M," fig. 1); one was killed by a tree toppling across an automobile, and two were electrocuted by fallen wires. One person died 8 days later from injuries received during the storm.

The damage throughout the path of the storm, while extensive, was not major as far as structural wind damage was concerned. A large share of the structural damage was caused by large trees falling on buildings and houses. About 3,000 trees were uprooted or broken off, bringing down power and telephone lines generally throughout the area. Toppling of huge trees, tall and with wide-spreading top branches, was aided by the supersaturated soil. Precipitation in thunderstorms late on May 11 and in the early hours of May 12, amounted to 1.76 inches at the airport. This heavy rainfall on ground already wet from an excess of precipitation this spring, produced a condition favorable for uprooting of trees. The City Forester stated, "At least 50 percent less trees would have toppled if the soil had not been so saturated. The trees that toppled had survived heavier winds in past storms."

A ground survey on May 13 and an aerial survey on May 14 indicated little or no scattering of debris. All of the trees were alined roughly parallel to each other and fell toward the southeast along the first 2 to 2½ miles of the path, and then generally easterly along the last 6 miles.

The damage varied considerably within the storm path. Figure 1 shows the path of damage and particular locations where damage was unusually severe. Damage estimates made by the three cities of Rocky River, Lakewood, and Cleveland, total approximately $8 million.—*H. N. Burke, MIC, WBAS, Cleveland, Ohio.*

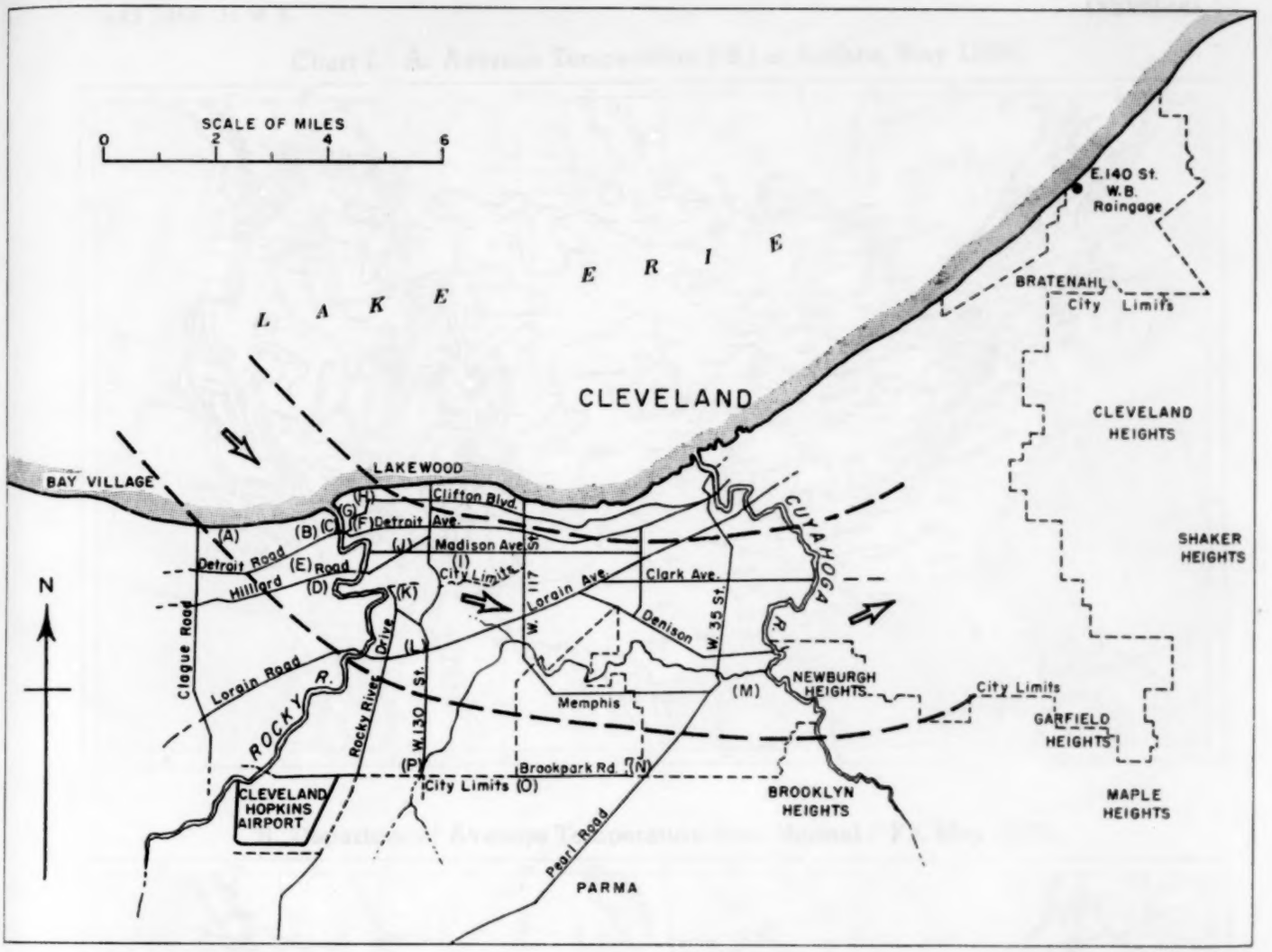


FIGURE 1.—*Sketch of Cleveland, Ohio, and immediate vicinity showing path of damage from thunderstorm, May 12, 1956. Lettered points sustained damage as follows:*

(A) Breezedale Cove, northwestern edge of Rocky River—Trees down, and garage down.

Clague Intake Cove:

—Bad damage to trees, house trailer overturned.

—Clock tower, Rocky River, overturned.

(B) Wagar and Lake—Trees fell from northwest to southeast.

(C) Rocky River business district:

—Westlake Hotel roof signs ruined; many windows out. Portion of roof blown off on northwest corner.

—Westlake Cab radio tower blown over.

—Bad damage to Rocky River business district plate glass windows; trees down all over, all lying toward southeast to east-southeast.

(D) Westmoor, Hilliard—Garage unroofed, large chimney of greenhouse blown over lying toward southeast with little or no scattering of bricks.

(E) Wagar and Erie—Many trees uprooted, house chimney blown off, garage down at Stratford and Wagar.

(F) Sloan and Lake Aves.—Bad damage to house caused principally by uprooted trees.

(G) Yacht Club Basin at Clifton Park—Many uprooted trees, car smashed, driver killed by falling trees; approximately 15 boats on winter props damaged at Cleveland Yacht Club.

(H) Clifton Park and Northwestern Lakewood—Numerous trees uprooted. Corner of Hall and Lake Avenue, utility pole broken off.

This point appears to be the eastern edge of the damage path along the immediate lake front. West and southwest of this point, the damage increases to a maximum on each side of the Rocky River valley.

(I) Bunts Rd., between Detroit and Lakewood Heights Blvd.—Trees down toward more easterly direction. Bunts and Madison, no apparent damage. West on Madison, increasing damage, particularly uprooted trees.

(J) Madison and Hilliard Rd.—Only minor damage, but gets worse as you move westward toward Riverside.

(K) Riverside from Hilliard to Kamms' Corners—Many large trees down, considerable structural damage to residences due to falling trees, some roofs partially torn off.

(L) West 137 and Lorain—Many plateglass windows smashed, numerous trees uprooted.

(M) 4103 Pearl Rd. SW.—Tavern roof blown off and walls collapsed; 3 people killed. Tavern was in an especially vulnerable position, the first block off bridge across Big Creek valley. The west-northwest winds had full sweep of valley prior to striking tavern.

Meyers Ave.-Fulton Rd. area—Considerable damage to houses due to fallen trees. Denison Ave., numerous trees uprooted.

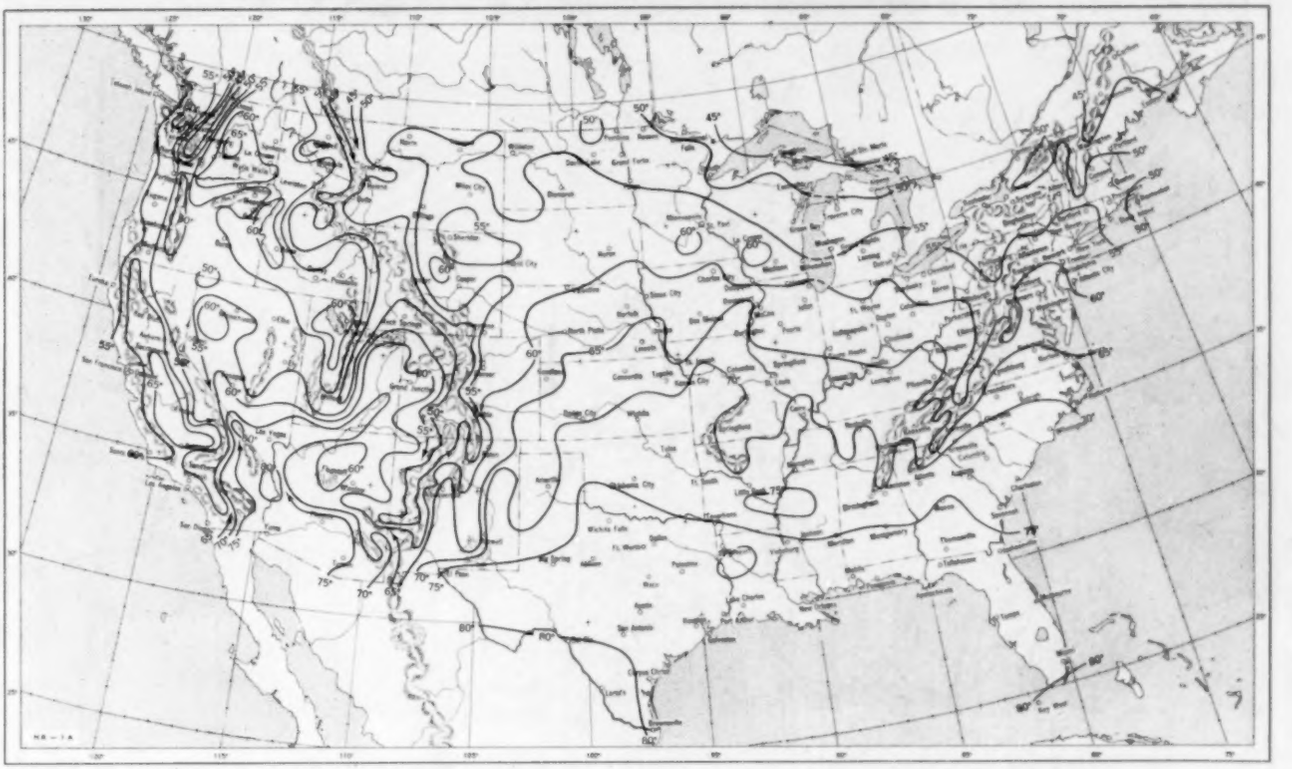
(N) Brookpark-Pearl Rd.—Serious fire damage to department store hit by lightning.

(O) Brookpark-Tiedeman Rd.—Only minor damage, small limbs broken off.

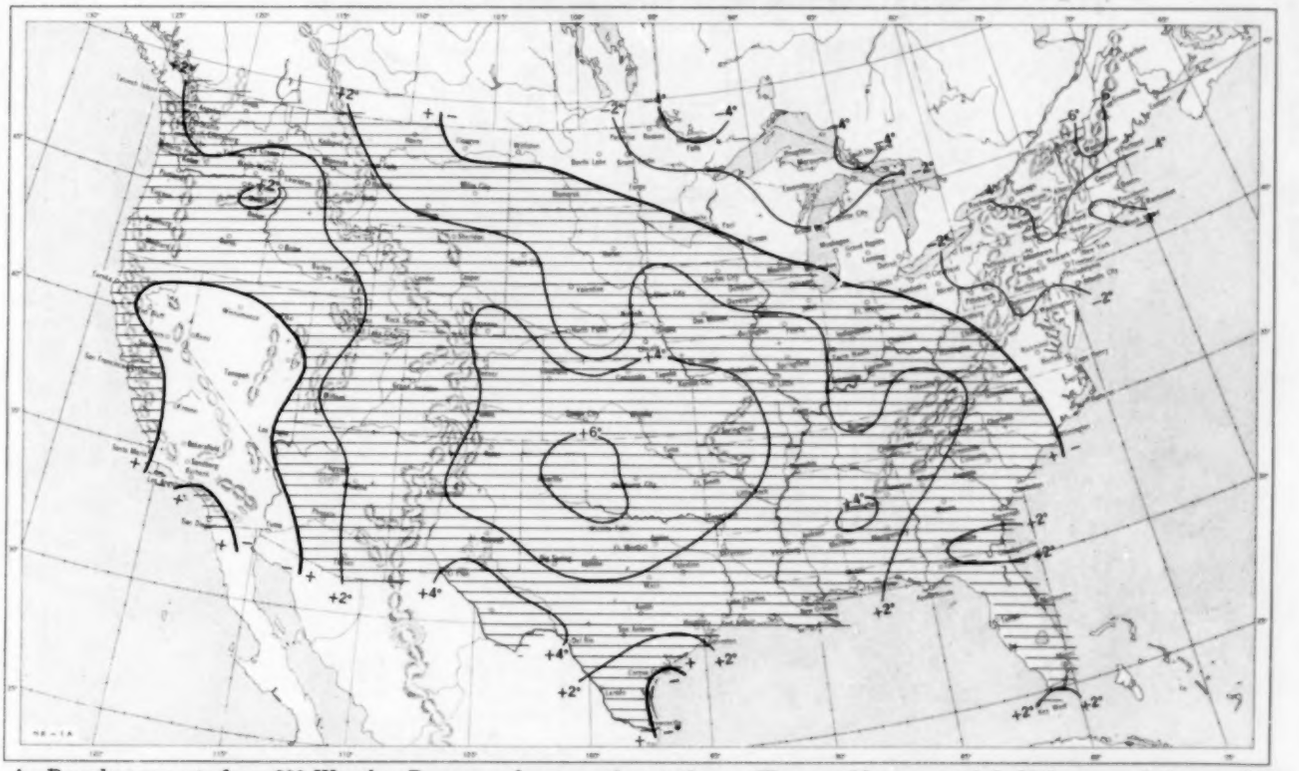
(P) Brookpark-West 130th St.—No damage.

U. S. GOVERNMENT PRINTING OFFICE: 1956

Chart I. A. Average Temperature (°F.) at Surface, May 1956.



B. Departure of Average Temperature from Normal (°F.), May 1956.



A. Based on reports from 800 Weather Bureau and cooperative stations. The monthly average is half the sum of the monthly average maximum and monthly average minimum, which are the average of the daily maxima and daily minima, respectively.
B. Normal average monthly temperatures are computed for Weather Bureau stations having at least 10 years of record.

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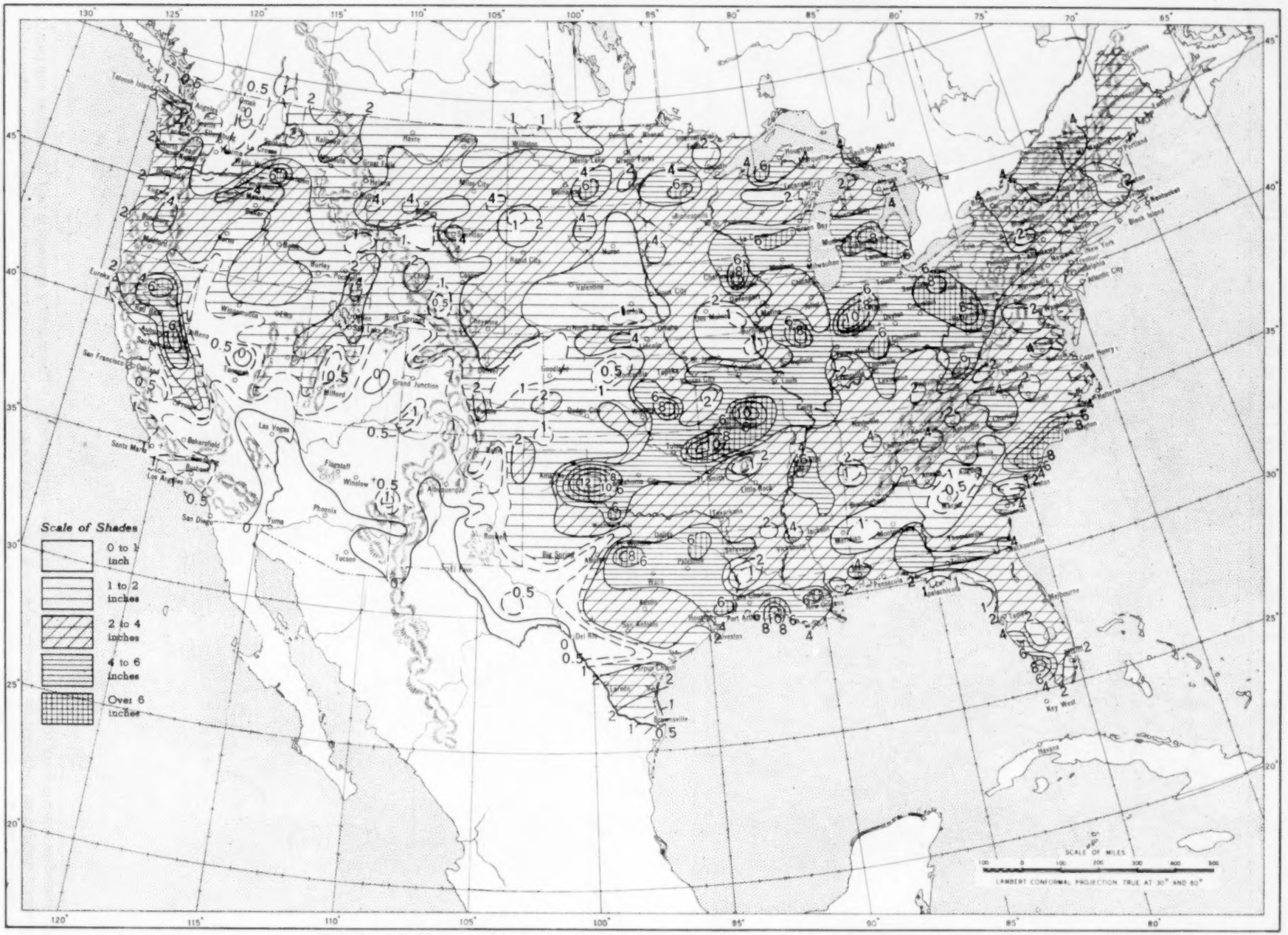
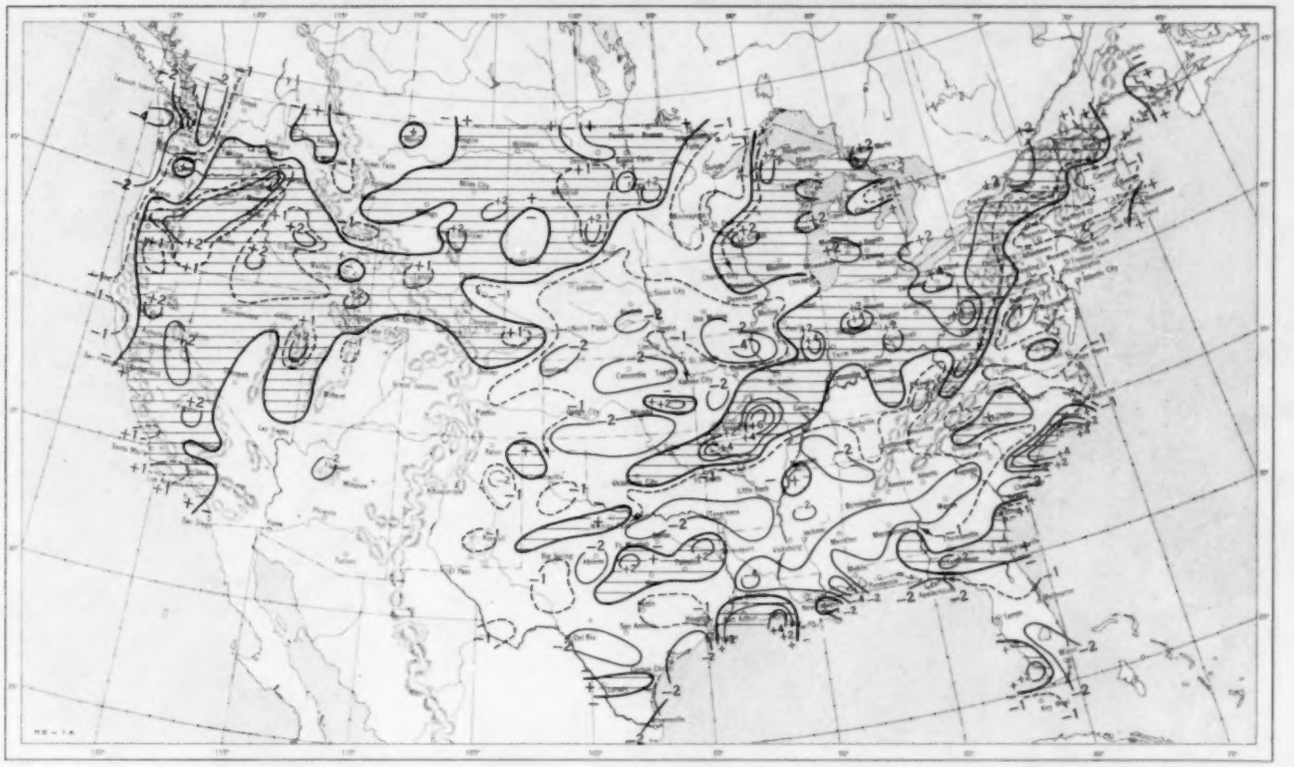
Chart II. Total Precipitation (Inches), May 1956.

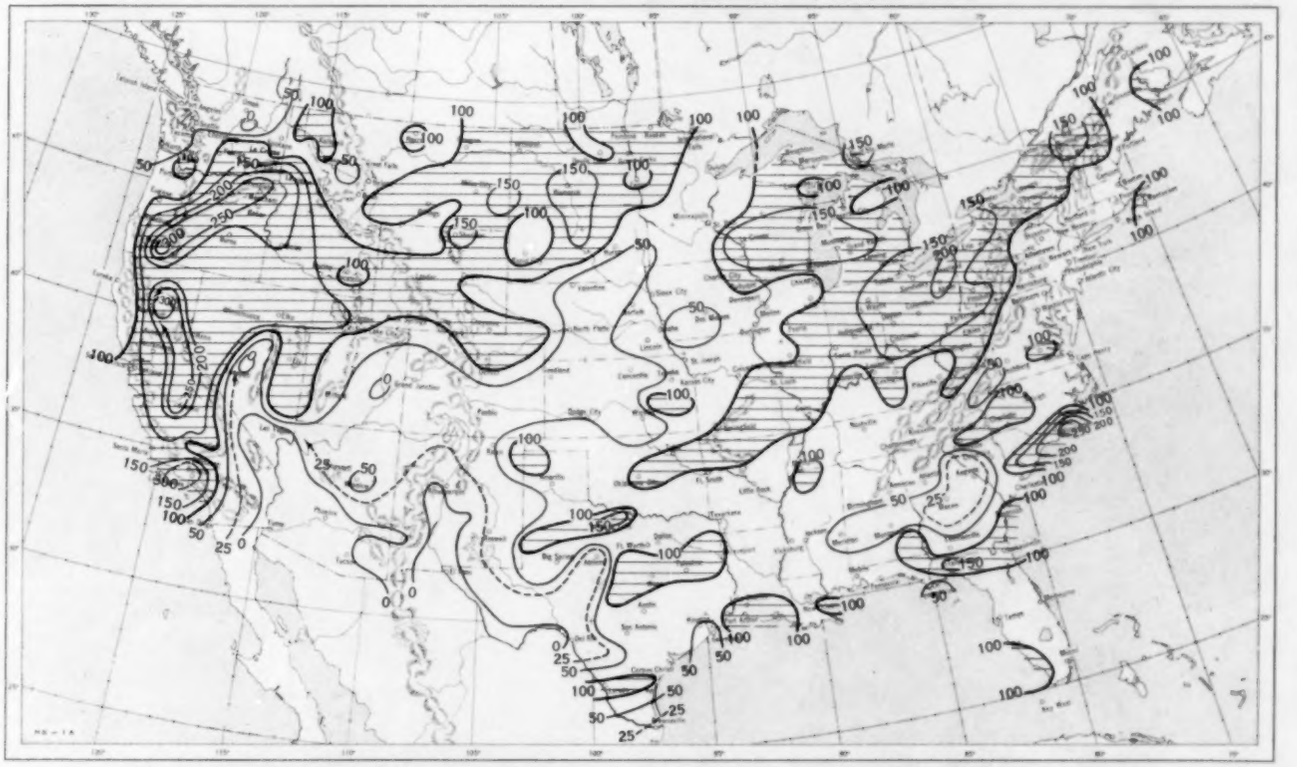

Scale of Shades
0 to 1 inch
1 to 2 inches
2 to 4 inches
4 to 6 inches
Over 6 inches
SCALE OF MILES
LAMBERT CONFORMAL PROJECTION, TRUE AT 30° AND 60°

Based on daily precipitation records at 800 Weather Bureau and cooperative stations.

Chart III. A. Departure of Precipitation from Normal (Inches), May 1956.

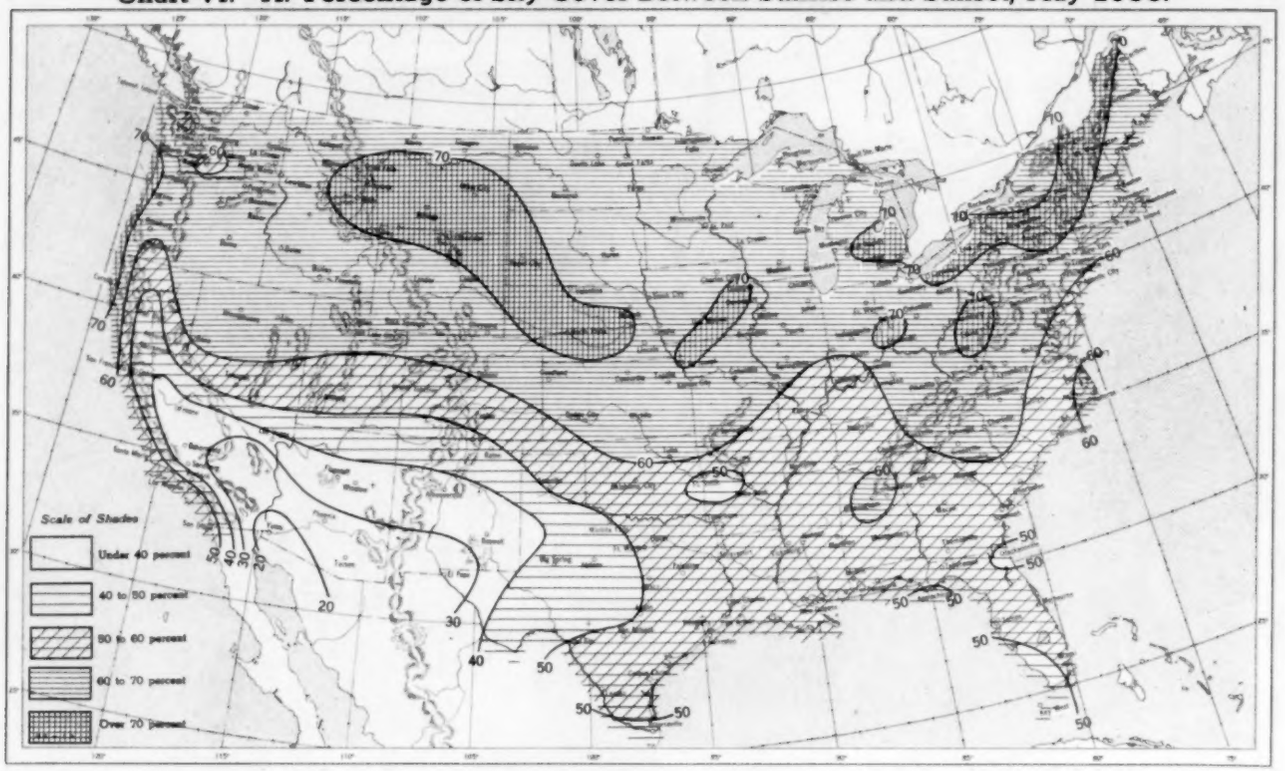


B. Percentage of Normal Precipitation, May 1956.

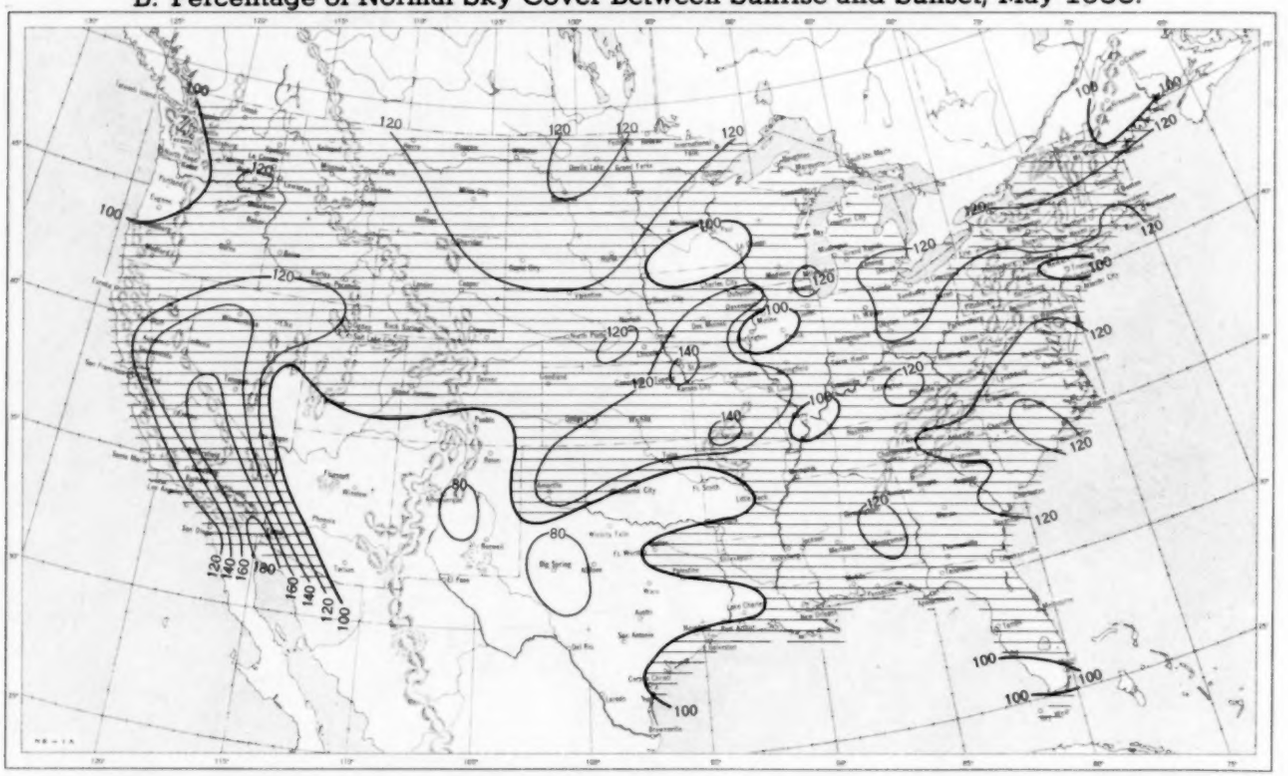


Normal monthly precipitation amounts are computed for stations having at least 10 years of record.

Chart VI. A. Percentage of Sky Cover Between Sunrise and Sunset, May 1956.

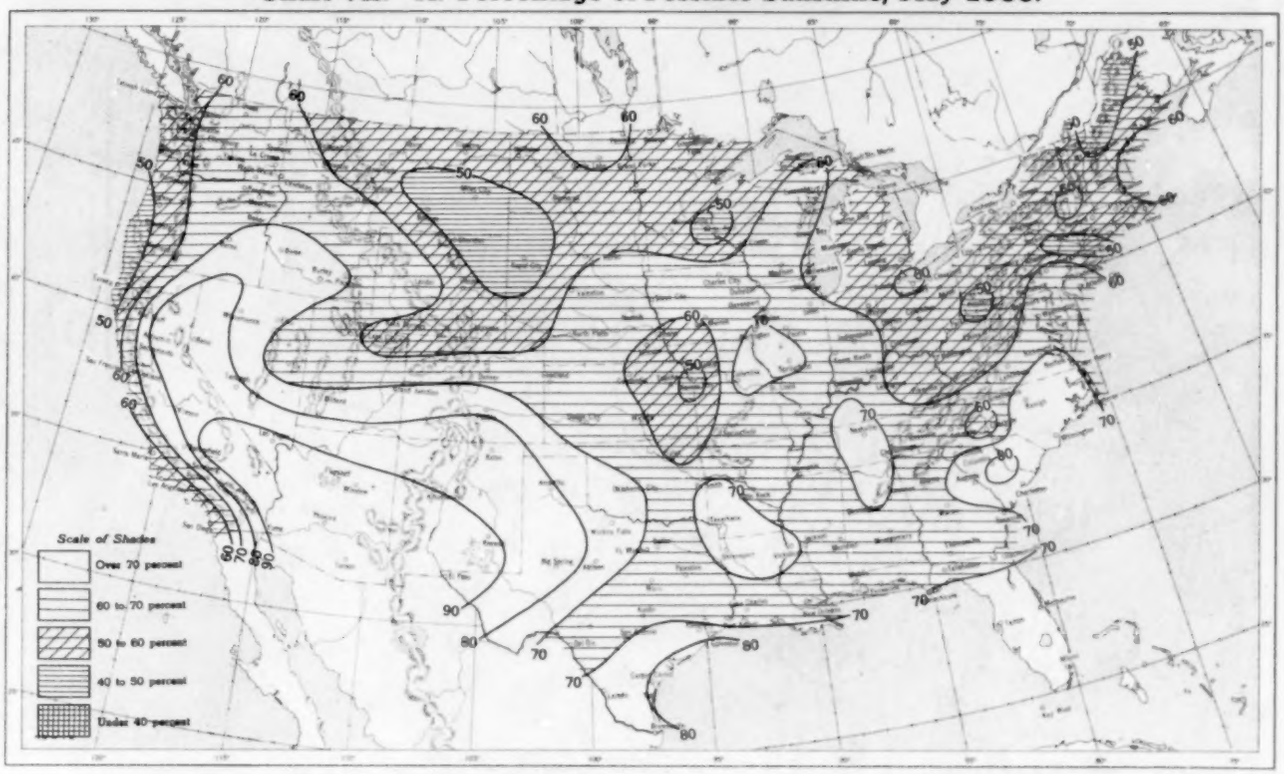


B. Percentage of Normal Sky Cover Between Sunrise and Sunset, May 1956.

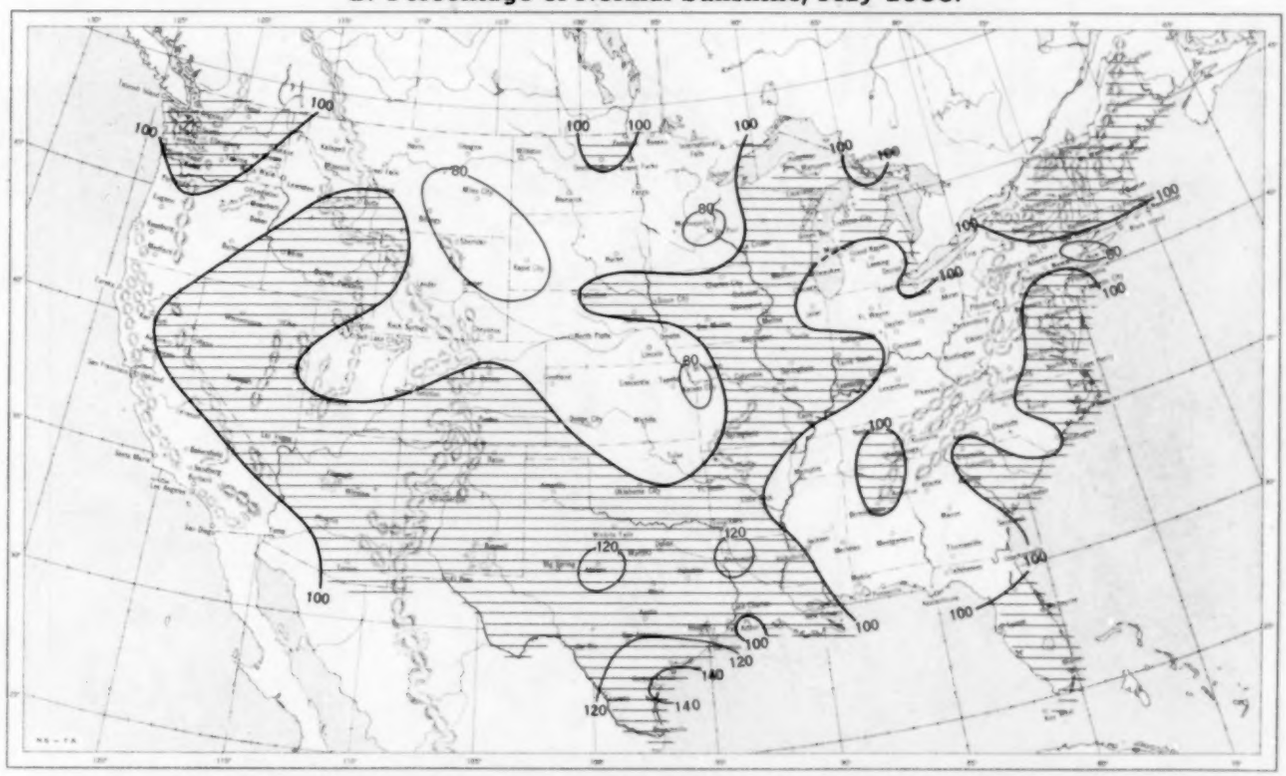


A. In addition to cloudiness, sky cover includes obscuration of the sky by fog, smoke, snow, etc. Chart based on visual observations made hourly at Weather Bureau stations and averaged over the month. B. Computations of normal amount of sky cover are made for stations having at least 10 years of record.

Chart VII. A. Percentage of Possible Sunshine, May 1956.



B. Percentage of Normal Sunshine, May 1956.



A. Computed from total number of hours of observed sunshine in relation to total number of possible hours of sunshine during month. B. Normals are computed for stations having at least 10 years of record.

Chart VIII. Average Daily Values of Solar Radiation, Direct + Diffuse, May 1956. Inset: Percentage of Mean Daily Solar Radiation, May 1956. (Mean based on period 1951-55.)

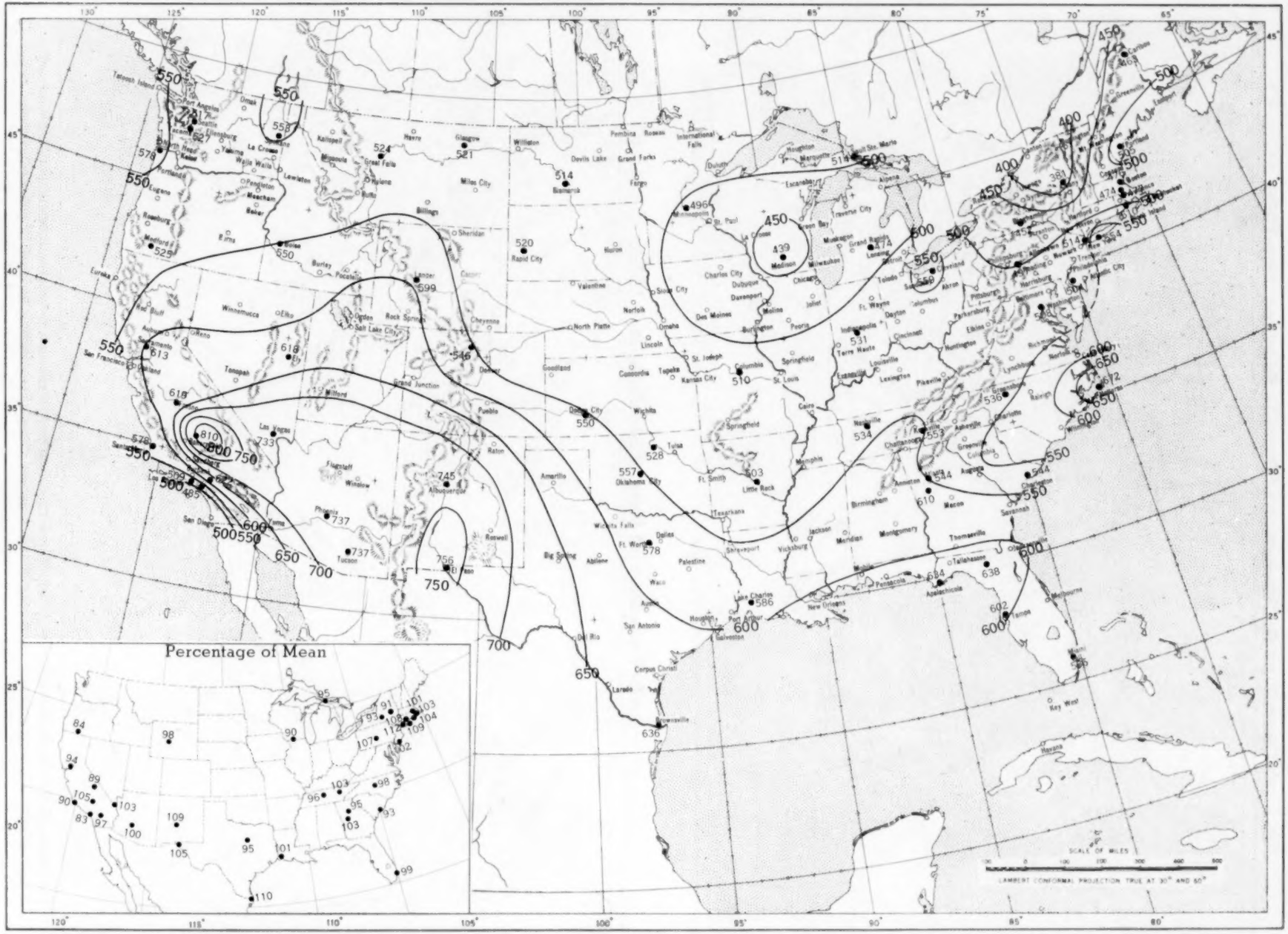
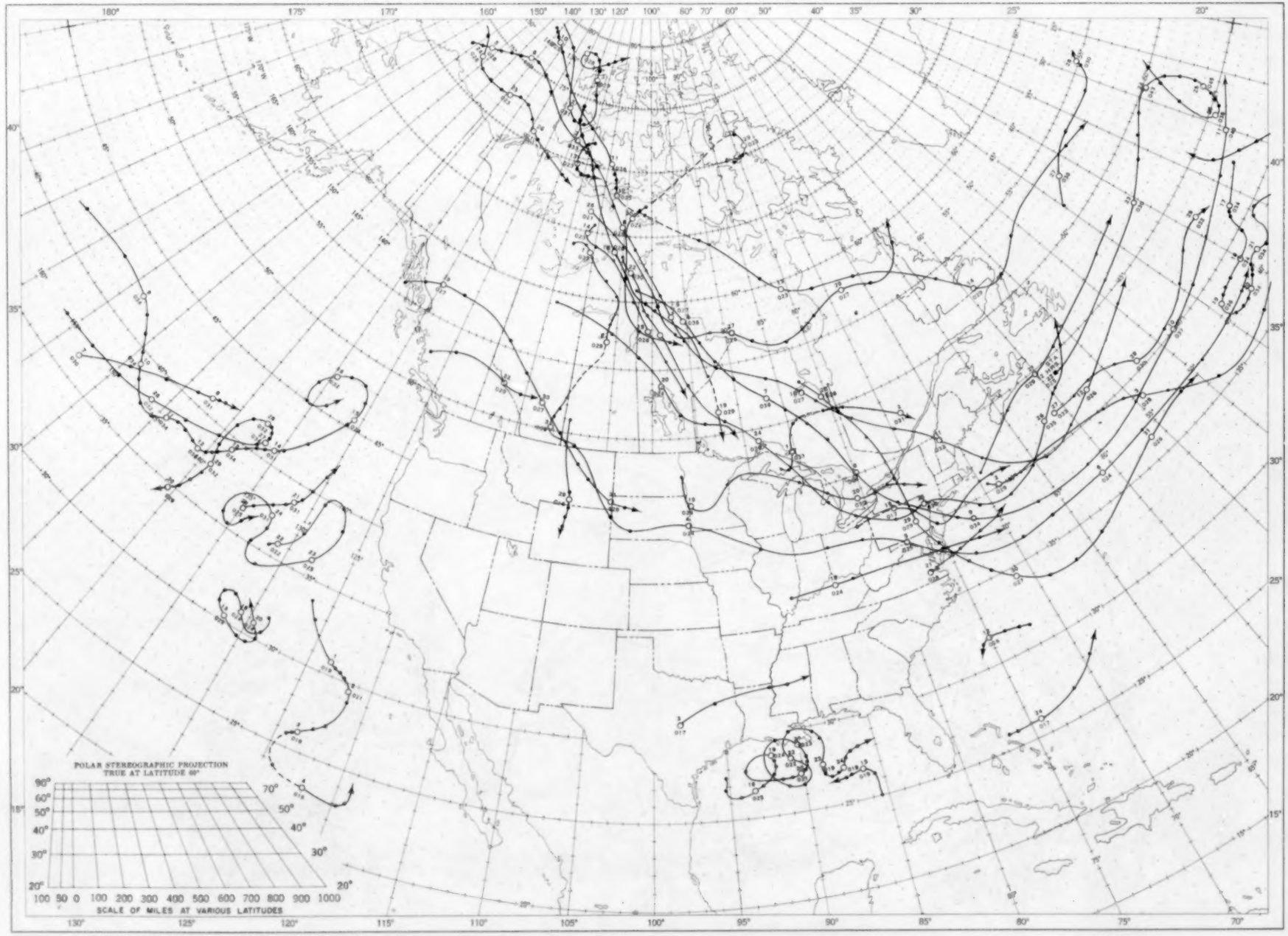


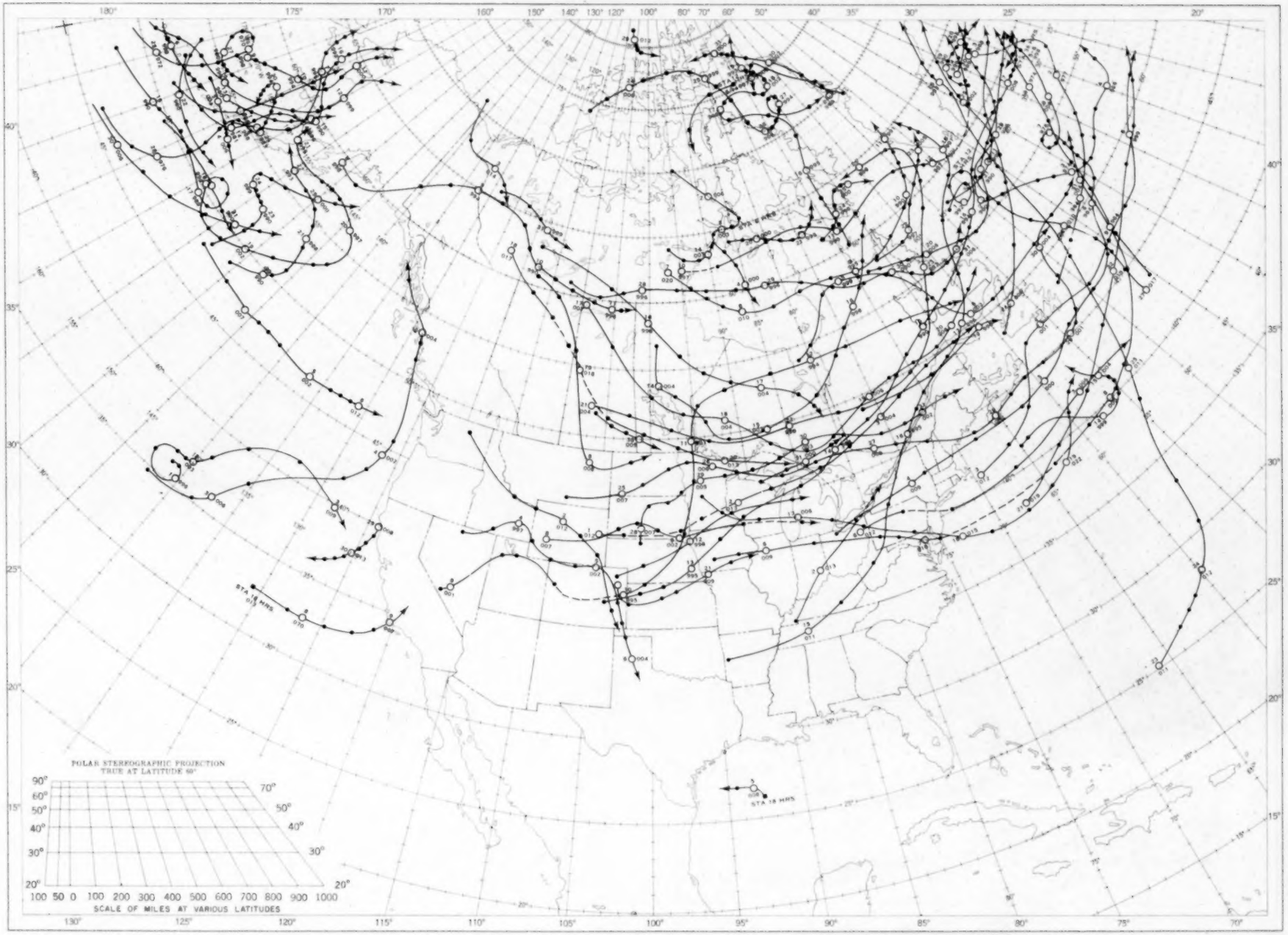
Chart shows mean daily solar radiation, direct + diffuse, received on a horizontal surface in langleys (1 langley = 1 gm. cal. cm. $^{-2}$). Basic data for isolines are shown on chart. Further estimates are obtained from supplementary data for which limits of accuracy are wider than for those data shown.

Chart IX. Tracks of Centers of Anticyclones at Sea Level, May 1956.


POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°
90° 60° 50° 40° 30° 20°
70° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900 1000
SCALE OF MILES AT VARIOUS LATITUDES

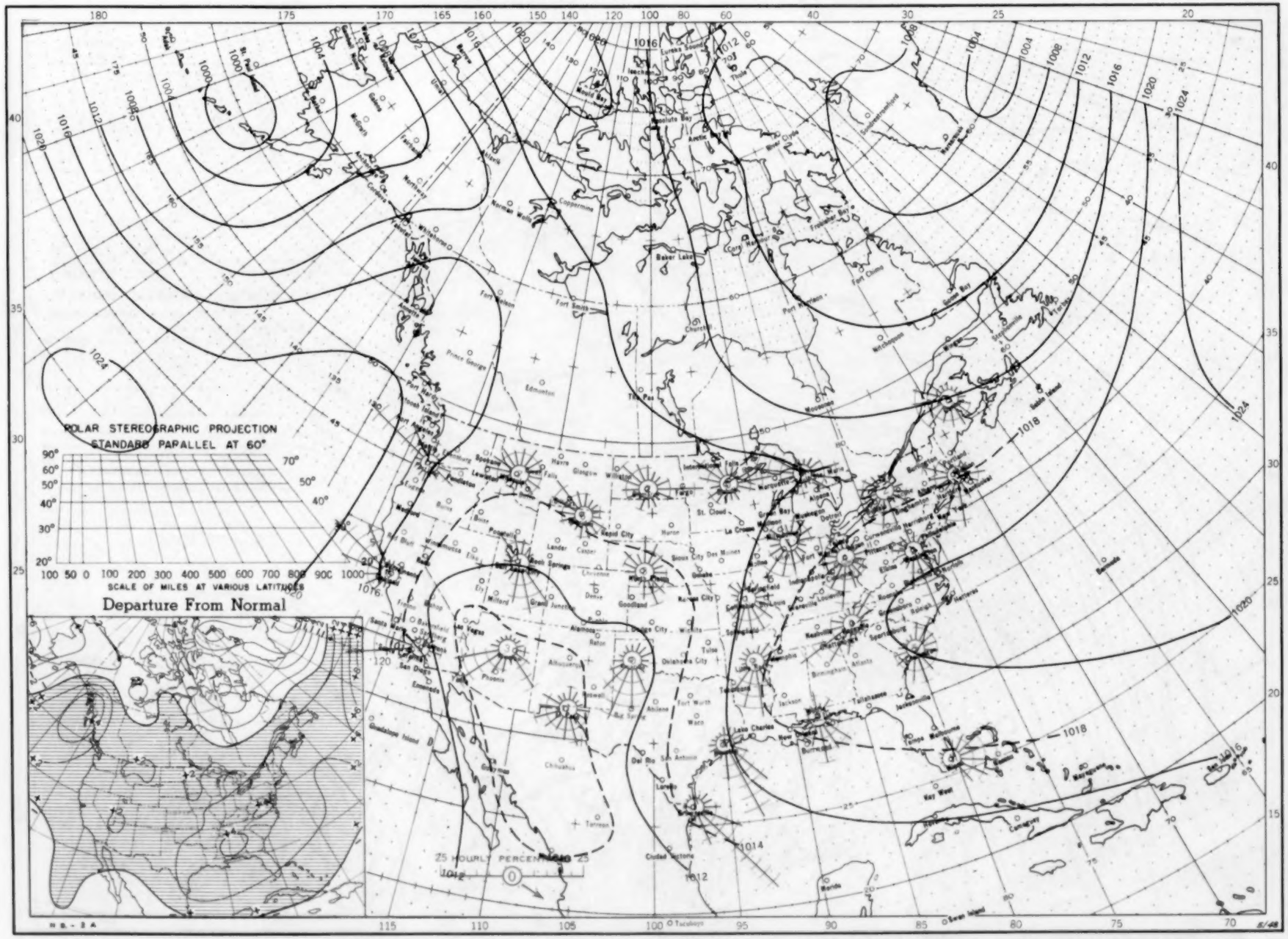
Circle indicates position of center at 7:30 a. m. E. S. T. Figure above circle indicates date, figure below, pressure to nearest millibar. Dots indicate intervening 6-hourly positions. Squares indicate position of stationary center for period shown. Dashed line in track indicates reformation at new position. Only those centers which could be identified for 24 hours or more are included.

Chart X. Tracks of Centers of Cyclones at Sea Level, May 1956.


POLAR STEREOGRAPHIC PROJECTION
TRUE AT LATITUDE 60°
90° 60° 50° 40° 30° 20°
70° 50° 40° 30° 20°
100 50 0 100 200 300 400 500 600 700 800 900 1000
SCALE OF MILES AT VARIOUS LATITUDES
STA 18 HRS.
STA 18 HRS

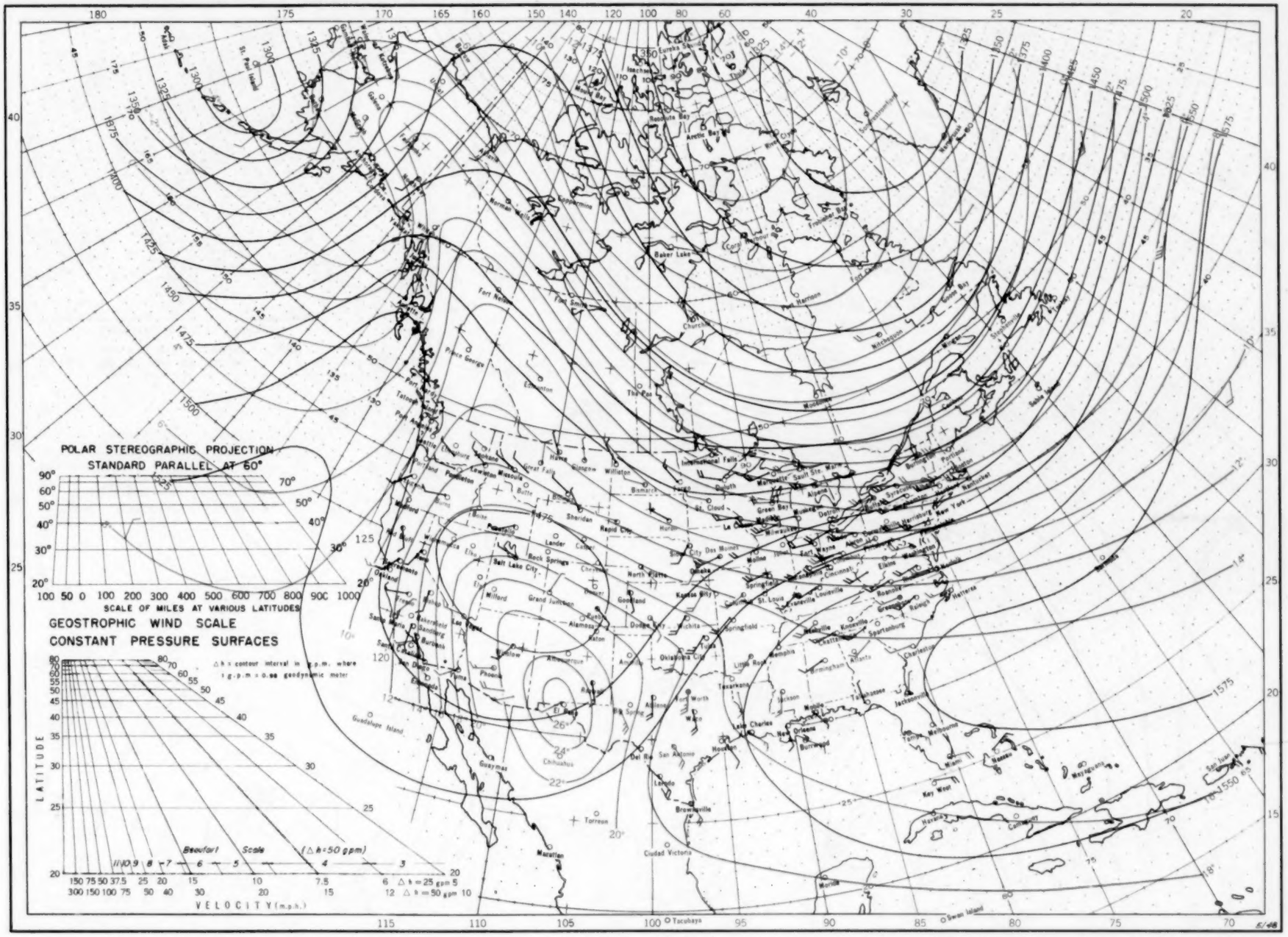
Circle indicates position of center at 7:30 a. m. E. S. T. See Chart IX for explanation of symbols.

Chart XI. Average Sea Level Pressure (mb.) and Surface Windroses, May 1956. Inset: Departure of Average Pressure (mb.) from Normal, May 1956.



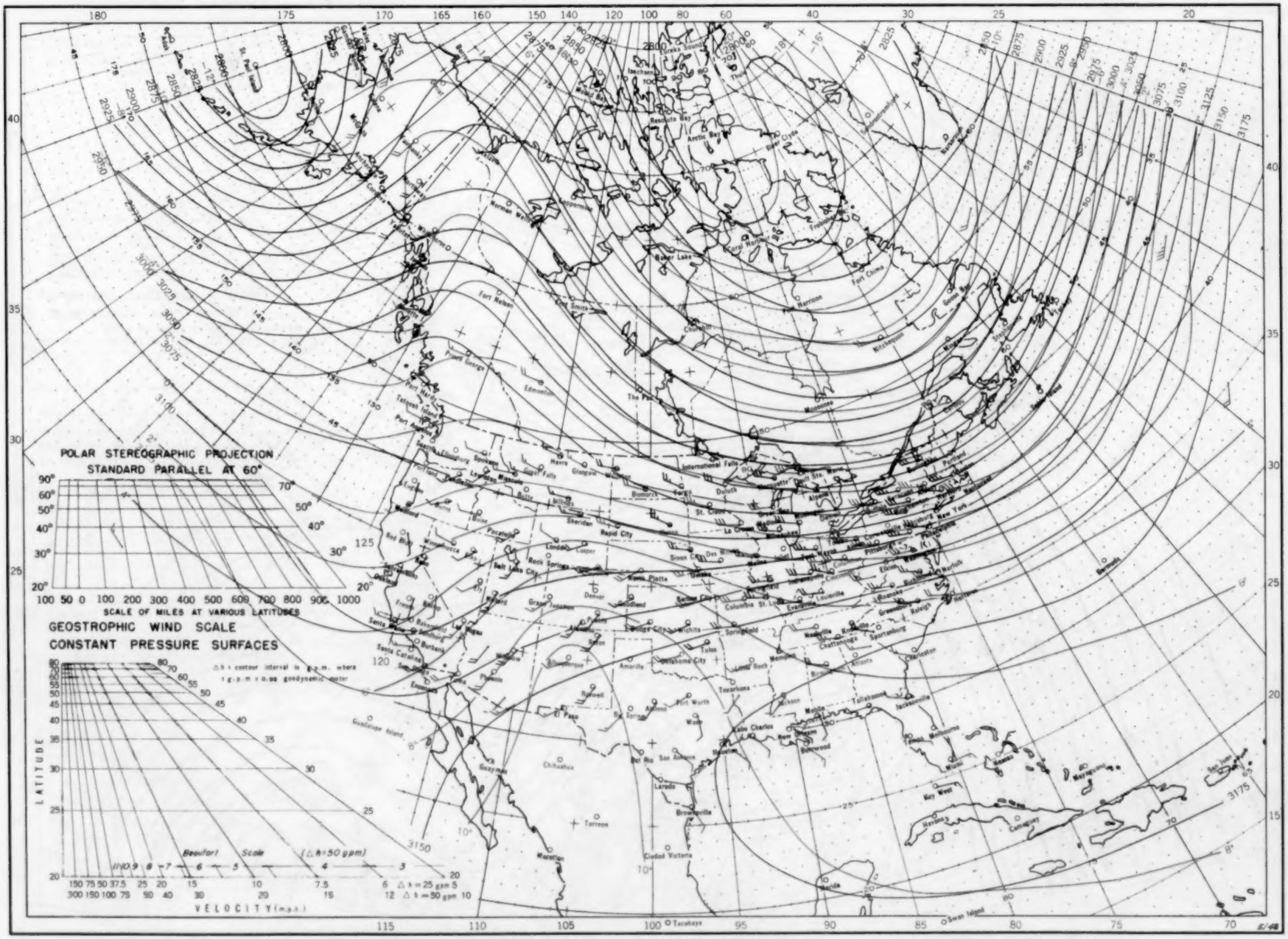
Average sea level pressures are obtained from the averages of the 7:30 a. m. and 7:30 p. m. E. S. T. readings. Windroses show percentage of time wind blew from 16 compass points or was calm during the month. Pressure normals are computed for stations having at least 10 years of record and for 10° intersections in a diamond grid based on readings from the Historical Weather Maps (1899-1939) for the 20 years of most complete data coverage prior to 1940.

Chart XII. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 850-mb. Pressure Surface, Average Temperature in °C. at 850 mb., and Resultant Winds at 1500 Meters (m.s.l.), May 1956.



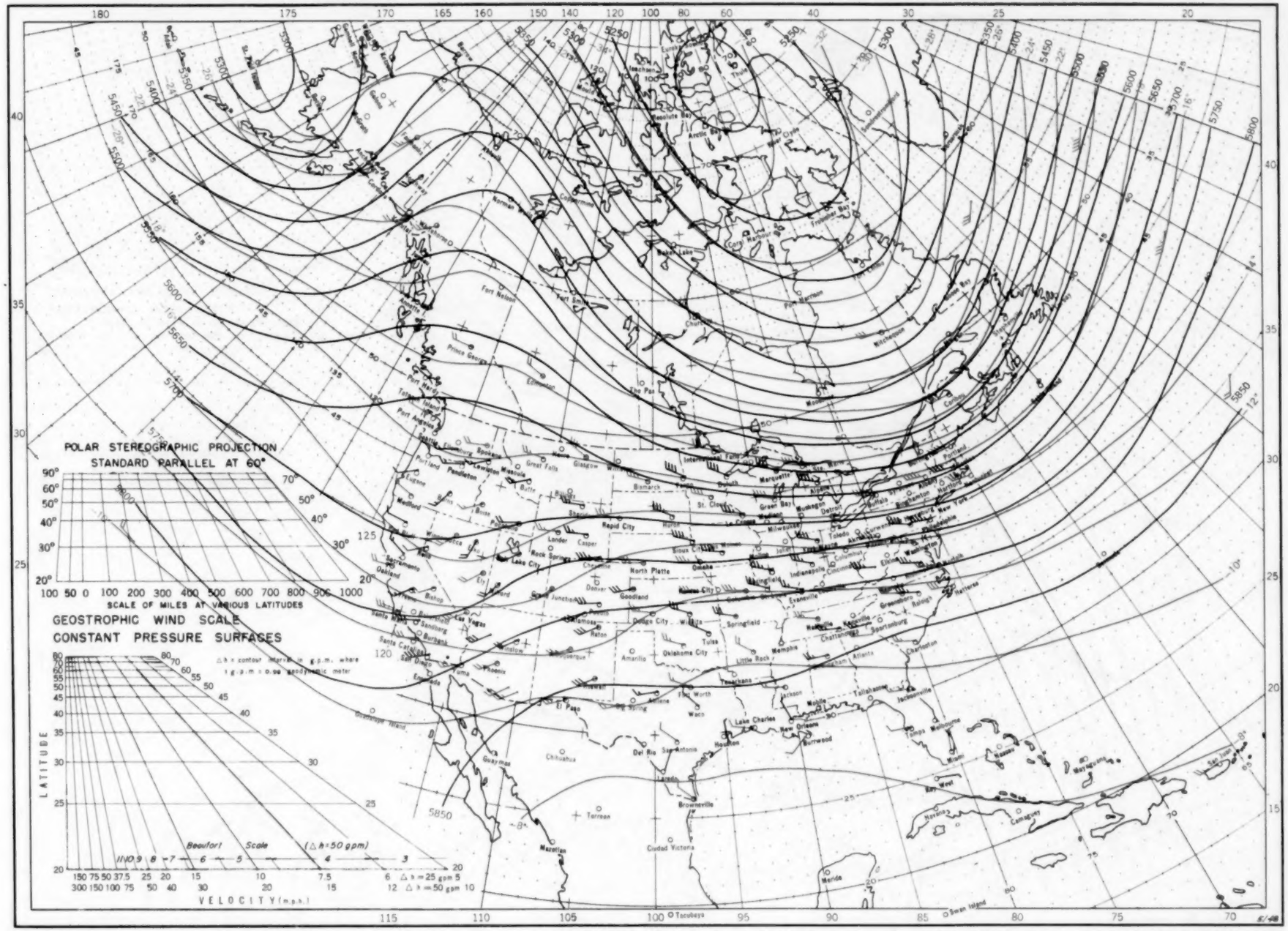
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIII. Average Dynamic Height in Geopotential Meters (1 g.p.m.. = 0.98 dynamic meters) of the 700-mb. Pressure Surface, Average Temperature in °C. at 700 mb., and Resultant Winds at 3000 Meters (m.s.l.), May 1956.



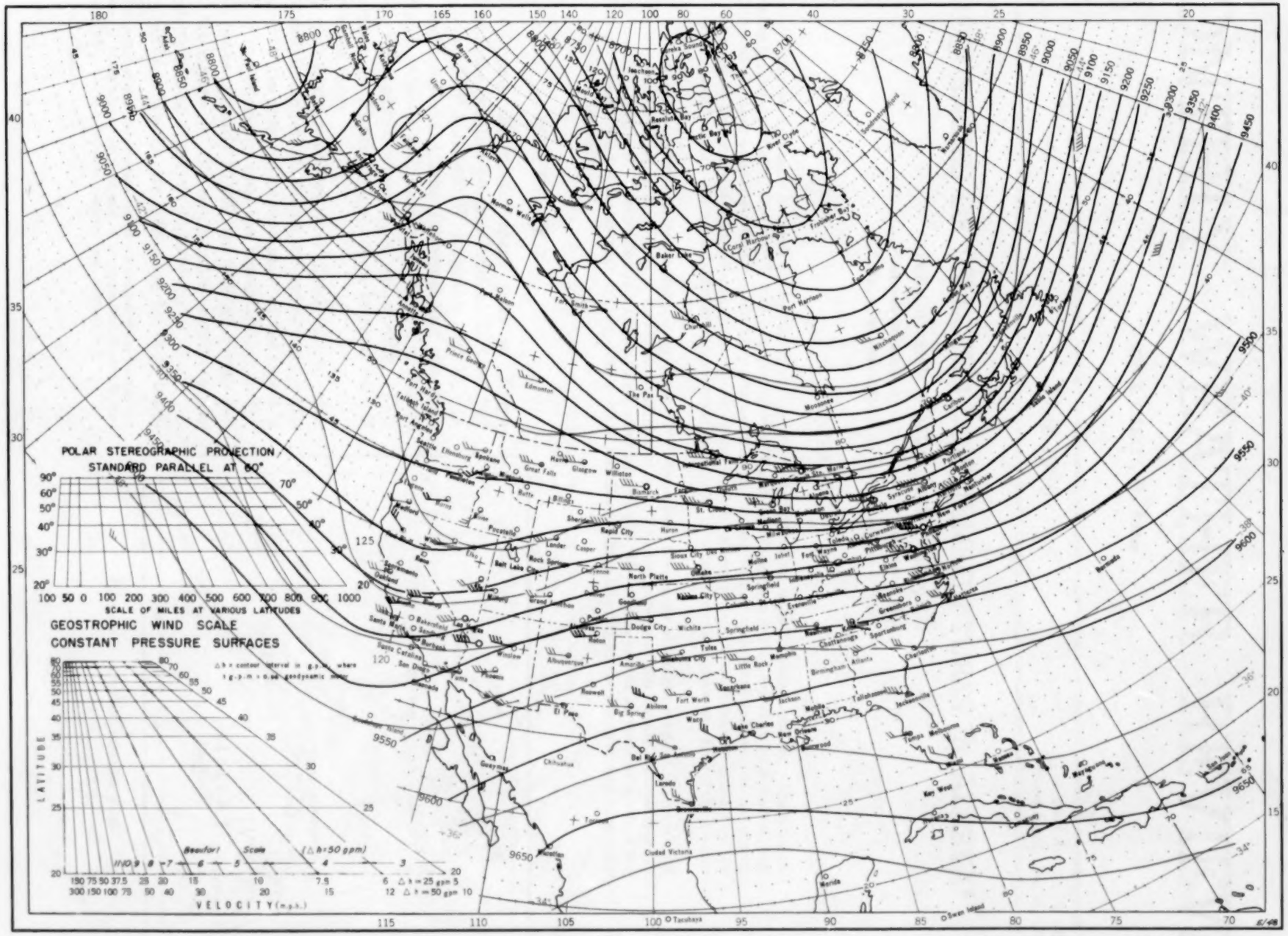
Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins taken at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.

Chart XIV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 500-mb. Pressure Surface, Average Temperature in °C. at 500 mb., and Resultant Winds at 5000 Meters (m.s.l.), May 1956.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. those shown in red are based on rawins at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; Wind barbs indicate wind speed on the Beaufort scale.

Chart XV. Average Dynamic Height in Geopotential Meters (1 g.p.m. = 0.98 dynamic meters) of the 300-mb. Pressure Surface, Average Temperature in °C. at 300 mb., and Resultant Winds at 10,000 Meters (m.s.l.), May 1956.



Contour lines and isotherms based on radiosonde observations at 0300 G. M. T. Winds shown in black are based on pilot balloon observations at 2100 G. M. T.; those shown in red are based on rawins at 0300 G. M. T. Wind barbs indicate wind speed on the Beaufort scale.